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ABSTRACT

The United States lunar laser ranging program utilizes two observatories, one of which is atop Haleakala on the island of Maui, Hawaii The Hawaii Institute of Geophysics has implemented a comprehensive geodetic-geophysical support program to monitor local and regional crustal deformation on the island of Maui The program includes repeated geodetic laser surveys between the LURE Observatory and an island-wide and inter-island networks, gravimetric surveys and first order levelling, also ocean tide gages, tiltmeters for monitoring the local vertical, and seismic surveillance of crustal activity, (Carter et al , 1977, Berg and Sutton, 1977)

This report describes the results of the first high-precision electronic distance measurements accomplished in the support program, the instrumentation used and instrument modifications, the procedures adapted, and the atmospheric conditions that preclude standard methods on long lines through an inversion layer

We aimed at an overall distance accuracy of 1 part in 10^7 for the individual lines This objective is reflected in the discussions and calibrations of the Rangemaster II, the laser distance measuring instrument used, the barometers and thermometers used to obtain atmospheric data on the ground and in the air by helicopter to determine the refractive index, and finally, in the calculation procedures

The report presents the actual laser-measured line lengths and new coordinate computations of the line terminals, and discusses the internal consistency of the measured line lengths Several spacial chord lengths have been reduced to a Mercator plane, and conditional adjustments on that plane have been made

The report also compares the old Hawaiian data and the new measurements, and discusses the relative merits of the direct integration versus modeling approach to obtain the mean refractive index along a laser line

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I INTRODUCTION

Background

Space age tools now push errors of positioning a point in an earth-wide reference system from the decimeter toward the centimeter level Resulting accuracies permit application of these tools to such esoteric problems as tectonic plate motion and (geologically) short-term dynamic interaction between areas of crustal generation and absorption by measurements of crustal deformation over short to very large baselines as a function of time These changes also can be related by the same techniques to variations in the position of the earth's pole of rotation and variations in the rotation rate

One of the most accurate techniques uses laser ranging from fixed observatories on earth to the retroreflectors installed by astronauts on the moon One of two United States observatories is operating at Haleakala on the island of Maui, Hawaii, situated on the Pacific plate The position changes with time of the lunar laser ranging station will include components of local and regional crustal deformation and tectonic plate motion Therefore, terrestrial geodetic and geophysical methods appear to be the most economical approach to determination of local and regional deformation, that have to be separated from the observatory position measurements relative to the moon or artificial satellites in order to ascertain the larger scale motions

The University of Hawaii's Institute for Astronomy has constructed and is operating the lunar laser ranging observatory at Mt Haleakala at an elevation of 3000 m The site was selected for its separation from the other U S lunar laser ranging site at MacDonald, Texas (on the North American tectonic plate) providing reasonable separation for polar motion studies and an opportunity to verify and measure any plate motion The Hawaii Institute of Geophysics of the University of Hawaii is implementing a comprehensive geodetic-geophysical support program to monitor local and regional crustal deformation on the island of Maui The program includes repeated geodetic laser survery between the LURE Observatory and an island-wide and inter-island networks, gravimetric surveys and first order levelling, also ocean tide gages, tiltmeters for monitoring the local vertical, and seismic surveillance of crustal activity, (Carter et al , 1977, Berg and Sutton, 1977)

This report describes in detail the results of the first high-precision electronic distance measurements accomplished in the support program, the instrumentation used, together with modifications, the procedures adapted, and the particular atmospheric conditions that seem to preclude more standard methods on long lines through an inversion layer The task of measuring the crustal deformation is particularly difficult because of the convex topography of Haleakala, precluding the use of "shooting" simple radial patterns to determine the strain ellipsoid

We aimed at an overall distance accuracy of 1 part in 10^7 for the individual lines This objective is reflected in the discussions and calibrations of the Rangemaster II, the laser distance measuring instrument used, the barometers and thermometers used to obtain atmospheric data on the ground and in the air by helicopter to determine the refractive index and finally in the calculation procedures

Subsequent chapters present the actual laser-measured line lengths and new coordinate computations of the line terminals, and probe the internal consistency of the measured line lengths The reduction of several spacial chord lengths to a Mercator plane and subsequent conditional adjustments on that plane have been executed

Another chapter is devoted to the comparison of the old Hawaiian data (partially dating back to 1876) and the new measurements presented here   The final chapter discusses the relative merits of the direct integration versus modeling approach to obtain the mean refractive index along a laser line

Accuracy Goals

The basic formulas relating frequency, velocity and wavelength in a medium are given by

$$\frac{\omega}{c} = \frac{2\pi}{\lambda} \quad \text{and} \quad c = \frac{c_o}{n} \qquad \text{(I-1)}$$

where ω = angular frequency = $2\pi f$

f = frequency

c_o = velocity in vacuum

c = velocity in medium with refractive index n

λ = wave length in medium

Eq 1 can be arranged

$$\lambda = \frac{c_o}{f} \cdot \frac{1}{n} \quad , \qquad \text{(I-2)}$$

In the distance measuring instrument, the light beam is modulated with a (radio band) frequency f   The number of modulation wavelengths between the laser and the target (and return path) are counted by the instrument (including fractions) to determine the distance

$$D_1 = \ell \cdot \frac{\lambda_1}{2} = \ell \frac{c_o}{2fn_1} = \ell \cdot 10 \text{ m} \qquad \text{(I-3)}$$

where D_1 = distance readout from instrument

ℓ = number of modulation wavelengths in path (including return)

f = modulation frequency

n_1 = assumed refractive index (determined by $n_1 = \frac{c_o}{2f} \quad \frac{1}{10}$)

Since the "true" refractive index is usually different from n_1, the "true" distance is given by

$$D_T = \ell \cdot \frac{\lambda}{2} = \ell \cdot \frac{c_o}{2f} \quad \frac{1}{n} = D_1 \cdot \frac{n_1}{n} \qquad \text{(I-4)}$$

where n = "true" refractive index, that is the mean value along the beam path   With the basic goal of about 1 part in 10^7 each of the factors in Eq (4) has to be determined at least to that accuracy that is ℓ and f in the Rangemaster II, C_o is given by international agreement (see Laurila, 1976, p. 129) and n depends on pressure, temperature and humidity measurements along the laser beam path.

In order to have "manageable" numbers the "refractive number" N is used, with the refractive index being

$$n = 1 + N \times 10^{-6} \qquad \text{(I-5)}$$

For all line calculations the following formula was used (Laurila, 1976, p. 132) for the refractive number

$$N = \frac{Ng \cdot P - 41.8e}{3.709T} \qquad \text{(I-6)}$$

where Ng = 300.2 the group refractive number for He - Ne laser light

P = barometric pressure (mb)
e = water vapor pressure (mb)
T = temperature in °K .

The basic goal of accuracy of 1 part in 10^7 (in n) permits no more error than 0.1 in N. The corresponding limits imposed on P, T and e then can be estimated from the partial derivatives of Eq. (6) with respect to these variables

$$\frac{dN}{dT} = \frac{1}{T^2}\left(\frac{-NgP + 41.8e}{3.709}\right)$$

$$\frac{dN}{dP} = \frac{Ng}{3.709T} \qquad \text{(I-7)}$$

$$\frac{dN}{de} = -\frac{41.8}{3.709T}$$

Some typical values of atmospheric data for Maui will show the required maximum error limits for temperature, pressure and water vapor pressure.

	At Sea Level	At Haleakala (3000m)	
Temperature	295°K	280°K	
Pressure	1014 mb	705 mb	
Water Vapor Pressure	22 mb	2-5 mb	
dN/dT	-0.941	-0.728	
dN/dP	0.274	0.289	
dN/de	-0.038	-0.040	

maximum allowable error for 0.1 change in N (or 1 part in 10^7 in n)

	At Sea Level	At Haleakala (3000m)	
m_T (temperature)	0.11°C	0.14°C	
m_p (pressure)	0.37 mb	0.35 mb	(I-8)
m_e (water vapor pressure)	2.6 mb	2.5 mb	

In discussing individual pieces of equipment, their calibration and basic limitations in the following sections, the reader should keep Eq. (4) in mind, where ℓ (number and fraction of wavelength measured), and f (modulation frequency) and their possible errors are associated with the Rangemaster II. The mean refractive index $\bar{n}$ is obtained from a number of n values determined along a measuring line including the end point where the accuracy of individual measurements (including calibration errors) for temperature, pressure and humidity should satisfy the maximum error allowance given in Eq I-8

II LASER LINE NETWORK

The location of lines and the setting of the terminal markers were completed prior to December 1976 The distance measurements were made during the period December 1976 to December 1977 Of the total of 38 lines provided with fixed terminal markers 31 have been measured, many of them several times The entire network on the island of Maui consists of 13 long lines with variable lengths between 8 and 31 kilometers, 5 intermediate lines of about 7 kilometers long in the vicinity of the top of Haleakala, 17 short lines of about 2 to 5 kilometers long and primarily used to tie tidal gages to inland markers, and finally 3 very short lines of a few hundred meters to tie the base of the LURE telescope to the network (Fig II-1) A general star format from the summit of Mt Haleakala to various points on the shoreline was utilized, ties between the loose terminals were made whenever possible Two complete quadrilaterals with diagonals have been formed, in the Wailuku-Haleakala and in the Hana Airport areas One extra center point was tied to the corner points in the former area The slope angles of the lines above horizontal vary between 0° and 12°

Prior to setting the terminal markers an extensive line of sight survey was conducted For each long and intermediate line elevation-distance increments, measured from the 1 24,000 quadrangle maps, were programmed and fed to an analog plotter Figs II-2 and II-3 illustrate samples of such plots Line Luke-ARPA represents a typical high-clearance line while Mees-Lighthouse is the line with the lowest clearance found in the network, both lines were flown by helicopter to determine the mean refractive index of the ambient atmosphere The results of the plots were verified during the actual survey on Maui

If available, U S Coast and Geodetic Survey (USGS), Hawaiian Government Survey (HGS) or Hawaiian Territorial Survey (HTS) triangulation markers have been used as the line terminals to allow comparison between the old trigonometric line lengths and the new laser line lengths Where new markers were needed, especially at the terminals of long lines, one-inch diameter holes were drilled in solid rocks or in existing and new concrete slabs and pillars Brass bolts 3/4-inch diameter and about 6 inches long with a flat end for fine marking have been anchored in the holes with epoxy The markers bear the identification of UH HIG and the number of the point At the end of most intermediate and short lines, holes 1/4-inch diameter and about 2 inches deep were drilled and phillips screws were set in lead bushing

Descriptions and specifications of all laser lines on the island of Maui are given in the following Table II-1

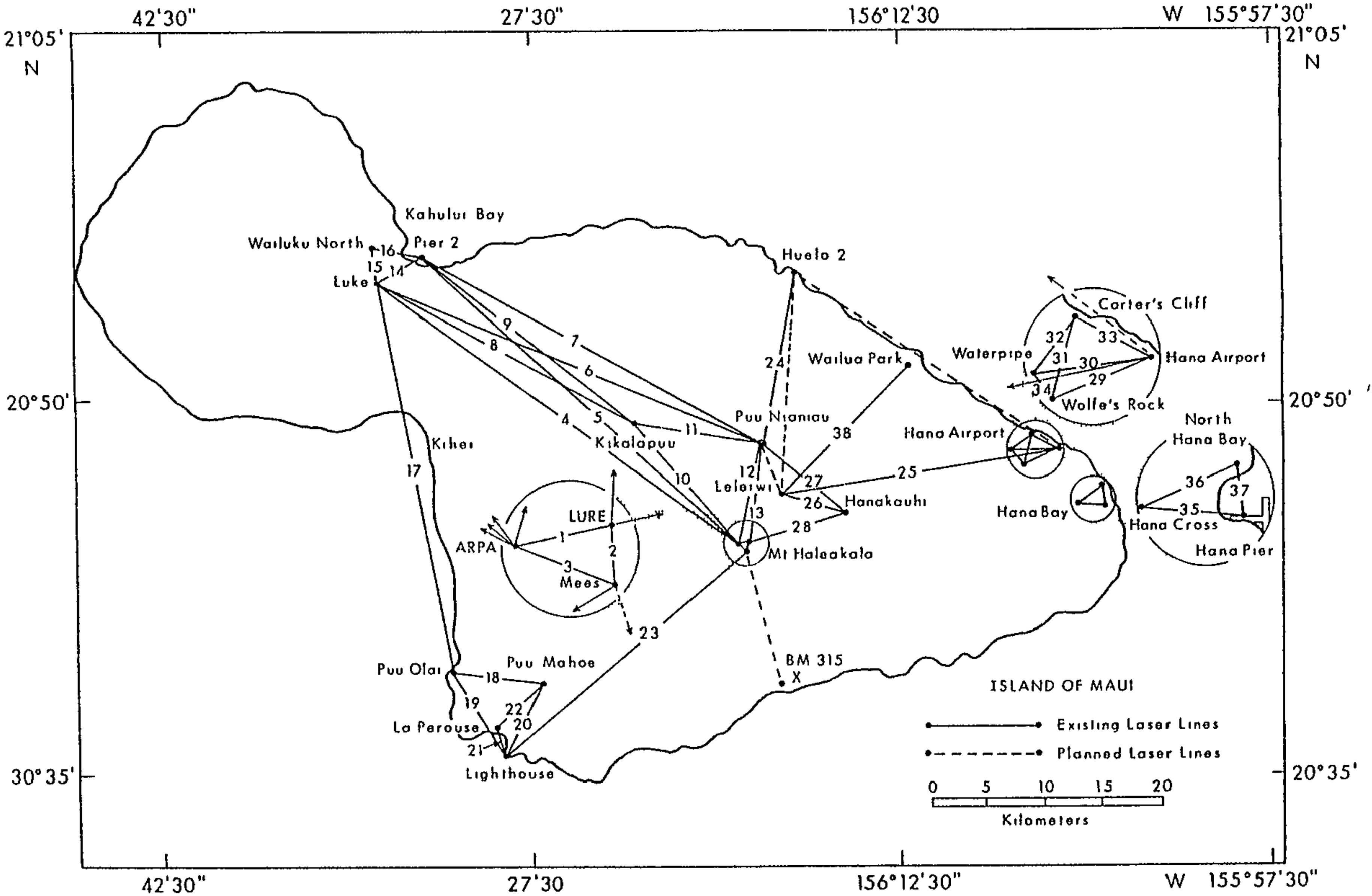
42'30"
27'30"
156°12'30
W 155°57'30"
21°05' N
21°05' N
20°50'
20°50'
30°35'
20°35'
156°12'30"
Kahului Bay
Wailuku North
Pier 2
Luke
16
15
14
Huelo 2
Carter's Cliff
Waterpipe
Hana Airport
32
33
31
30
29
34
Wolfe's Rock
Wailua Park
9
7
8
6
24
4
5
11
Puu Nianiau
38
Kikalapuu
Kihei
17
10
12
Leleiwi
27
26
Hanakauhi
25
Hana Airport
North Hana Bay
36
37
35
Hana Bay
Hana Cross
Hana Pier
LURE
1
ARPA
2
3
Mees
13
28
Mt Haleakala
23
BM 315
X
Puu Olai
Puu Mahoe
18
19
22
20
La Perouse
21
Lighthouse
ISLAND OF MAUI
Existing Laser Lines
Planned Laser Lines
0
5
10
15
20
Kilometers

Fig II-1

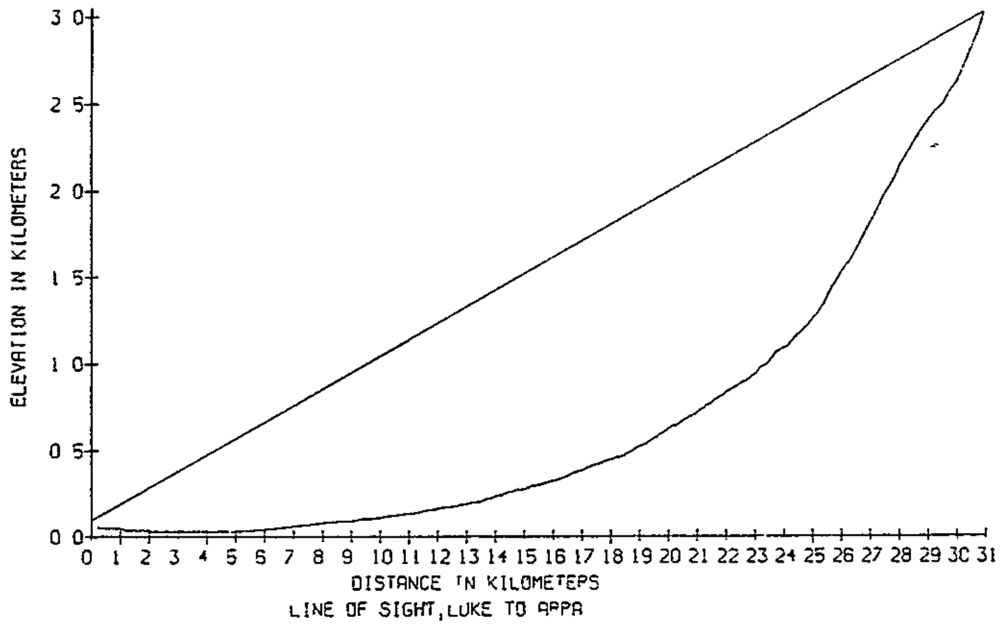

Fig II-2

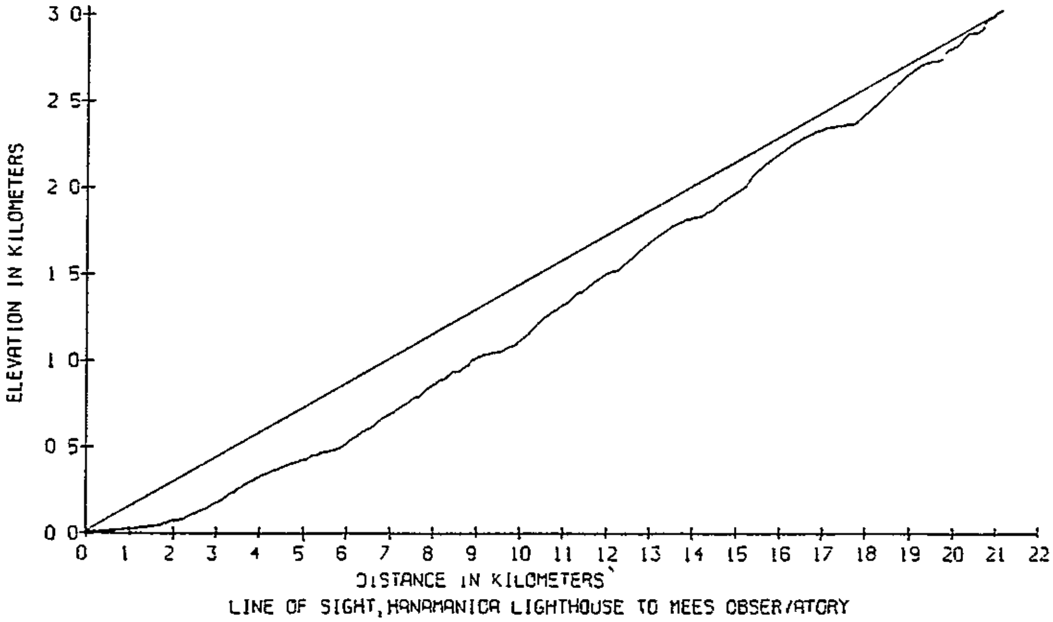

Fig. II-3

TABLE II - 1

Description of Laser Lines on the Island of Maui

No	Length km	Terminals			
		Identification	Elevation km	Location	Remarks
1	0 227	ARPA	3 03434	US Army Corps of Engineers marker in concrete slab 50 m west of ARPA west dome	On the marker
		LURE	3 04974	UH brass marker in flushed concrete	Middle of road, 15 m north of Kolekole
2	0 120	LURE	3 04974		
		Mees	3.04099	UH brass marker on concrete slab	15 m west of Mees Solar Observatory
3	0 248	Mees	3 04099		
		ARPA	3 03434		
4	31,398	ARPA	3 03434		
		Luke (Cemetery)	0 09384	UH brass marker next to USCGS 1912 marker	In a 4-feet square concrete slab
5	30,291	ARPA	3 03434		
		Pier 2	0 00228	UH screw marker next to USGS bench mark No 8	About 10 m NE from Kahului tidal gauge
6	28,843	Puu Nianiau	2 08790	HGS 1877 VABM	On the marker
		Luke	0 09384		
7	27,069	Puu Nianiau	2 08790		
		Pier 2	0 00228		
8	20,699	Kikalapuu	0 75540	USCGS 1950 VABM	On the marker
		Luke	0 09384		
9	19,349	Kikalapuu	0 75540		
		Pier 2	0 00228		
10	11,111	Kikalapuu	0 75540		
		ARPA	3 03434		
11	8,745	Kikalapuu	0.75540		
		Puu Nianiau	2 08790		
12	7,279	ARPA	3 03434		
		Puu Nianiau	2 08790		

TABLE II - 1 (cont)

No	Length km	Terminals			Remarks
		Identification	Elevation km	Location	
13	7,349	LURE	3 04974		
		Puu Nianiau	2 08790		
14	3,274	Luke	0 09384		
		Pier 2	0.00228		
15	2,469	Luke	0 09384		
		Wailuku North	0 09970	At the signal mast of the HTS 1929 marker	Fixed plastic reflector
16	3,482	Pier 2	0 00228		
		Wailuku North	0 09970		
17	27,459	Luke	0 09384		
		Puu Olai	0 10960	UH brass marker next to HGS 1879 marker	In a 4 feet square concrete slab
18	5,883	Puu Manoe	0 62850	UH screw marker in concrete support of cattle guard	On road, SW from Puu Mahoe VABM
		Puu Olai	0 10960		
19	6,900	Puu Olai	0 10960		
		Lighthouse	0 01463	UH brass marker in old concrete winch base	About 50 m NW from Hanamanioa Light
20	5,590	Puu Mahoe	0 62850		
		Lighthouse	0 01463		
21		Lighthouse	0 01463		
		La Perouse	0 00100	UH screw marker in lava rock	About 200 m SE from tidal gauge, marked with pile of lava boulders
22	4,513	Puu Mahoe	0 62850		
		La Perouse	0 00100		
23	21,408	Mees	3 04099		
		Lighthouse	0 01463		
24		Puu Nianiau	2 08790		
		Huelo 2	0 01120	UH marker next to HTS 1950 VABM	To be set on an existing concrete slab

TABLE II - 1 (cont)

No	Length km	Terminals			
		Identification	Elevation km	Location	Remarks
25		Leleiwi	2 68682	UH brass marker on concrete	On the floor of covered lookout site
		Hana Airport	0 01680	HTS 1950 VABM (Honokalani 2)	On the marker
26		Leleiwi	2 68682		
		Hanakauhi	2 71486	UH marker next to USCGS 1950 VABM	Fixed reflector at aluminum pipe
27		Puu Nianiau	2 08790		
		Hanakauhi	2 71486		
28		LURE	3 04974		
		Hanakauhi	2 71486		
29	3,024	Wolfe's Rock	0 12996	UH screw marker in rock	Rock is by a post in field 5 m off the road
		Hana Airport	0 01680		
30	3,474	Waterpipe	0 15240	UH screw marker in concrete	Concrete block under 3" waterpipe running through field 15 m off the road
		Hana Airport	0 01680		
31	1,990	Wolfe's Rock	0 12996		
		Carter's Cliff	0 01524	UH screw marker in rock	2 m from edge of cliff (under rock pile)
32	1,987	Waterpipe	0 15240		
		Carter's Cliff	0 01524		
33	2,353	Hana Airport	0 01680		
		Carter's Cliff	0 01524		
34	629	Wolfe's Rock	0 12996		
		Waterpipe	0 15240		
35	1,344	Hana Cross	0 16500	UH screw marker in concrete	At the NE corner of base of Cross monument
		Hana Pier	0 00300	UH screw marker in concrete	At the base of Hana Pier

TABLE II– 1 (cont)

		Terminals			
No	Length km	Identification	Elevation km	Location	Remarks
36	1,562	Hana Cross	0 16500		
		North Hana Bay	0 00300	UH screw marker in rock	About 6 m from water's edge along West Trail from house
37	912	Hana Pier	0 00300		
		North Hana Bay	0 00300		
38		Leleiwi	2 68682		
		Wailua Park	0 14905	UH brass marker in underground concrete pillar	Wailua Valley Lookout, edge of parking space

III INSTRUMENTATION

(Description, accuracies, calibration)

Geodimeter M8

The specified accuracy of the AGA Model 8 Geodimeter is ± (6 mm + 1 ppm) The frequency accuracy is ±0 5 ppm

With the Model 8 one "range measurement" (not including any corrections) actually consists of 32 individual range measurements (four frequencies x four phases x internal and external paths) and over 60 mathematical operations and over 30 logic decisions Thus, gathering data for one range computation takes at least a half hour to one hour, depending on conditions, and the calculations are not only time consuming, but prone to errors One obvious difficulty is that if the refractive index is drifting during the time that the data is collected, the resulting range measurement will reflect the mean value over that period, and there is no indication of the degree of drift from the range data A second difficulty is that if some difficulty is encountered at some point in the measurement, or if some procedural error is made, this may not be apparent until the attempt is made to reduce the data

Numerous methods were used to minimize the errors First, we doubled the number of data points Then the order in which the readings were taken was selected so that linear drifts would tend to cancel Once the distance was calculated using all four frequencies, it was recalculated using each frequency singly This gave some indication of atmospheric and instrumental drift, and gave individual checks for each of the four wavelengths We also measured each of the four frequencies periodically against a frequency standard to correct for oscillator drifts Finally, a program was developed for an HP-67 calculator that handled all of the calculations and logic decisions so that the data could be quickly checked in the field None of the data was used for the final line lengths, since no helicopter data were taken at the time

Rangemaster II

Since two wavelength or three wavelength distance measuring equipment is rather bulky for field surveys (Bouricius and Earnshaw, 1974, Slater and Huggett, 1976), we acquired the portable Rangemaster II (18 kg) for actual line measurements on the Hawaiian island of Maui

Description

The Rangemaster II is one of the latest electronic distance measurement systems, manufactured exclusively for the Keuffel & Esser Company by Laser Systems and Electronics, Inc in Tullahoma, Tennessee Extensive use of integrated circuits and a microprocessor make up a fully automated, low power consumption and easily portable system This system uses a 5m W helium neon red laser, which is modulated in the HF range Specifications are for an accuracy of ± 5 mm ± 1 ppm over a temperature range from -28° to +49°C after a 5 to 20 minute warmup depending on ambient temperature The readout resolution is 1 mm on the range display The operation of the instrument is based on range measurements at 4 modulation radio frequencies to obtain distance within a 10-km frame A correction for atmospheric conditions can be included during internal calculation for the distance readout The assumed difference from the refractive index of one for internal distance calculation (with the dial set to 0 ppm correction) is 310 ppm (That is $C_0/2f = 1\ 00030984 \cdot 10$ m, with 10 m the basic length unit, where $C_0 = 299792458$ m/sec and $f = 14984980$ Hz, for the Model 8 geodimeter the basic length unit is 5 m and $f = 29970000$ Hz leading to an assumed refractive index of 1 00030850) It should be noted that the Rangemaster II generates the basic frequency of 14984980 Hz as an upper side band of the 14983481 5 Hz internal oscillator

In the automatic mode a distance measurement is obtained (as an average of 100 rangings at the reference frequency) about every 8 sec, which compares to about 3/4 of an hour per measurement (plus additional time for data reduction) with the Model 8 geodimeter Therefore, averaging over many measurements would allow considerably better accuracy than the ± 5 mm ± 1 ppm if the reference frequency were known better than 1 ppm, and if the deviation from true distance in the 10-m base interval (± 5 mm) due to nonlinearities in the phase comparison by the pulse counting method were measured and corrected for

Another limiting factor for our application, especially during the measurement of the shorter lines, is thermal and shot noise of the detector The intensity of the light reaching the detector directly on long lines (∿ to 60 km) or through the attenuating gray wedge on short lines results in an electrical signal just high enough above noise to produce range measurements with a standard deviation of about 1 5 mm This standard deviation was actually measured on a 10-to 20-m line length in the laboratory On the long lines this noise is generally much less than the spread in measured length generated by atmospheric flicker and drift (with time) and the additional uncertainty in determining the mean refractive index along the laser beam path On shorter lines the spread due to detector noise becomes quite significant, since atmospheric flicker is small, and the refractive index more accurately determined and the resulting correction proportionately smaller On the shorter lines more reflected light is available and the optical attenuator (the gray wedge) is used to reduce its intensity at the detector to near noise level

Instrument Tests and Improvements

To increase the accuracy of the length measurement a number of tests and physical improvements were made These concern the oscillator frequency, the nonlinearity over the basic 10-m range and the thermal and shot noise limits

Thermal and Shot Noise

To reduce the standard deviation of a length measurement on the shorter lines a two-step attenuator was installed after the detector amplifier Thus attenuating the output electrical signal by a factor of 2 or 4 requires the same increase of light intensity at the detector, resulting therefore in an equal signal to noise improvement at the front end Thus with the electrical attenuator the statistics of the shortline measurements are practically reduced to the one-count least significant digit uncertainty of 1 mm

Reference Frequency (Laboratory Tests)

Since the main source of the 1-ppm limit is the reference oscillator, temperature dependence was investigated by placing a high-precision thermistor (15 K Ω at 25°C) inside the instrument casing directly on the module of the temperature-compensated crystal oscillator and measuring the reference frequency as a function of the thermistor resistance Despite some thermal inertia of the oscillator module it was found that the frequency could be determined from the thermistor readings (and a small additional factor dependent on supply voltage) to within ± 1 part in 10^7, which is a considerable improvement over the ± 1 ppm specification Further simplification will result by installing a more precise oscillator (± 5 x 10^{-9}/day) The full use of this instrumental capability, however, requires very careful monitoring of the atmospheric conditions in order to obtain the integrated refractive index over the measuring line

The Rangemaster II has a BNC output connector permitting the check of the nominal 14984980 Hz reference frequency The actual frequency during all laboratory and cold room tests was measured, using the 1 MHz output of a Tracor (Sulzer Laboratories Division) Model 304-B rubidium frequency standard as a reference The counting was accomplished with Hewlett Packard counter system combination of the Measuring System 5300A, Counter Section 5302A and Digital to Analog Converter 5311B The D/A output was recorded on a HP 7101B recorder Counting during 10-sec intervals resulted in a 10-Hz span for the 25-cm chart width in steps of 0 1 Hz (approx 7 parts in 10^9) Chart speed during the tests was 5 mm/minute The resistance of the thermistor was measured on a 3½-digit multimeter and data points were taken in steps of 0 1 K ohms at the time when the corresponding digit had settled at the display Similarly the battery supply voltage was measured with a 3½-digit multimeter to the nearest 0 01 volt with changes being noted on the frequency chart also The rubidium standard output was set to the 1968 time scale, which amounts to a -300 x 10^{-10} frequency offset from today's standard (BIH 1975 Table 9, p B-41) This offset, however, is smaller than the accuracy aimed for (1 part 10^7) during this test, and therefore was neglected In different terms all results presented refer to the 1968 standard

Several test runs were made starting with the instrument in thermal equilibrium at ambient office temperature (around 22 to 23°C) and some were made starting with the instrument in near equilibrium in a cold room at 0°C During all experiments there occurred a relatively fast frequency change over the first three to four minutes, which is considered the "warm up" time Afterwards the frequency related to the thermistor readings within ± 1 part in 10^7 at nearly constant ambient temperature and for repeated runs on the same day (a new run being started after the instrument was shut off sufficiently long to reach thermal equilibrium with the ambient temperature), each successive run seemed to be at slightly higher frequency However, when the instrument was shut off for a somewhat long time (overnight) the next day's run was found to be within a few least digit counts (0 1 Hz) of the previous day's first run This finding suggests that the oscillator does not age when shut off The oscillator seems to reach a nearly stable equilibrium at constant ambient temperature after about 2 hours The cold room (0°C) frequency-thermistor resistance curves differed from the office (22°C) curves by some 2½ Hz lower, indicating that the themistor as implemented does not completely track all frequency determining components of the oscillator, indicating differing temperature gradients between the thermistor and critical parts of the oscillator circuit One should perhaps include an ambient temperature correction of about 0 1 Hz/°C to the curves between 0 and 25 ambient temperature in order to stay within better than 1 part in 10^7 This temperature range is sufficient for field operations in Hawaii To assure this narrow range, an absolute frequency check should be run before and after each day's (or night's) field measurements

Before plotting the curves presented in Figures III-1 and III-2, a voltage correction of + 2 9 Hz/volt variation from a nominal 12 5

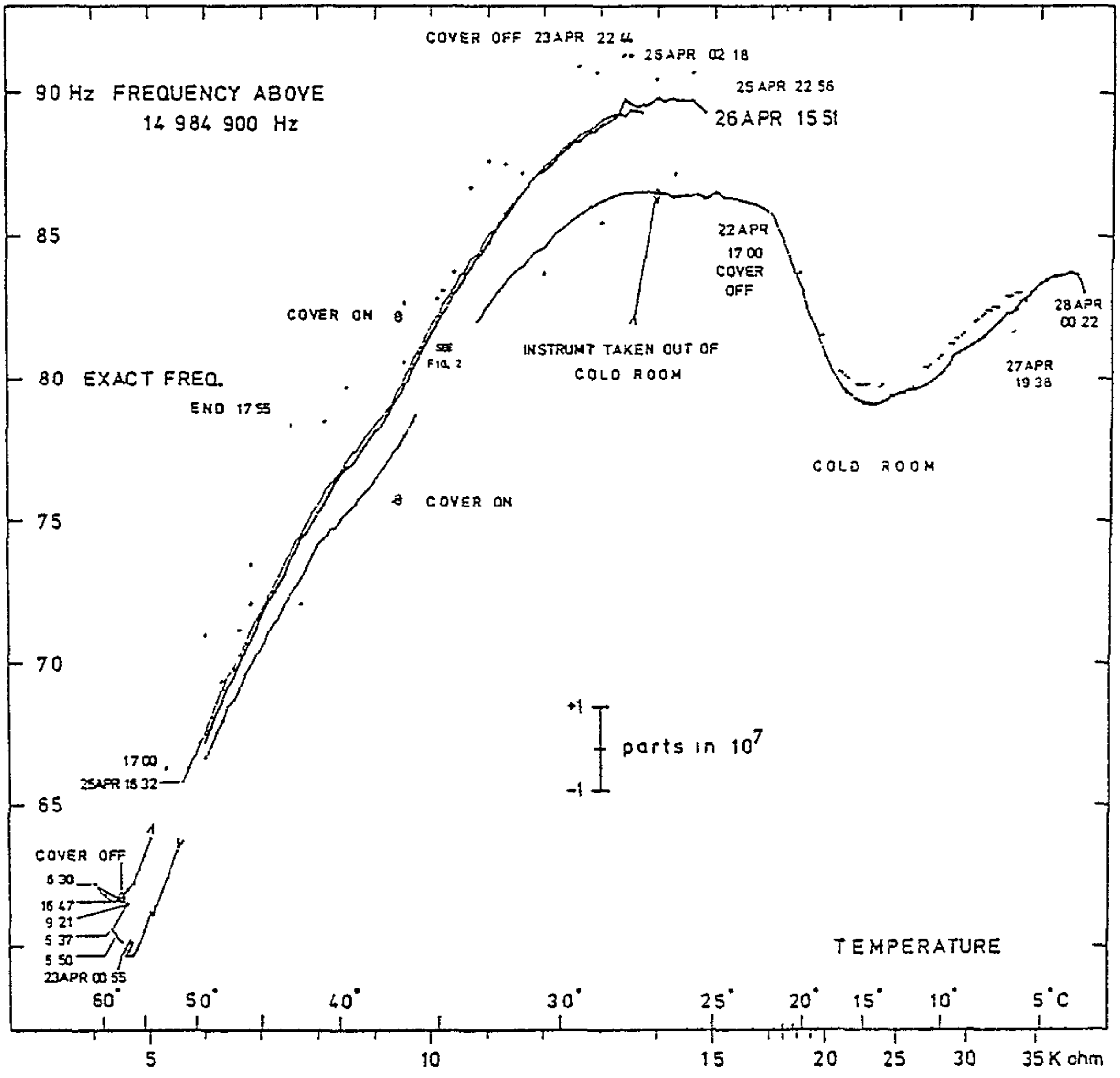
COVER OFF 23APR 22 44
25APR 02 18
25 APR 22 56
26APR 15 51
90 Hz FREQUENCY ABOVE
14 984 900 Hz
85
22 APR
17 00
COVER
OFF
COVER ON 8
SEE
FIG. 2
INSTRUMT TAKEN OUT OF
COLD ROOM
28 APR
00 22
27 APR
19 38
80 EXACT FREQ.
END 17 55
COLD ROOM
8 COVER ON
75
70
+1
parts in 10^7
-1
17 00
25APR 16 32
65
COVER OFF
6 30
16 47
9 21
5 37
5 50
23APR 00 55
TEMPERATURE
60°
50°
40°
30°
25°
20°
15°
10°
5°C
5
10
15
20
25
30
35 K ohm

Fig III-1

volts was applied This coefficient is an average of several determinations when the oscillator was stabilized and the voltage then varied (without a significant change in thermistor resistance reading), and is needed because the oscillator subassembly is operated directly from the (unregulated) battery voltage

One of the tests was started in the cold room, when near equilibrium (at 14 K Ω thermistor resistance or 27°C) was reached, the instrument was taken out into normal ambient temperature and measurements continued As Fig III-1 indicates, the frequency-resistance curve shows a gradual convergence toward the ambient normal temperature curves (22°-23°C) and is within 1 part in 10^7 at the resistance reading of 6 K Ω when the experiment was stopped

During a 24-hour run, starting (22 APR 17^H00) with the outside cover removed from the instrument and later replaced, indications were that longer operation (overnight) at higher temperatures either age the crystal positively or thermal effects occur that are not tracked by the thermistor (see 4 to 5 K Ω region (60°C) in Figure III-1) The cover was then taken off again to cool the instrument and the resulting curve continued at somewhat higher frequency The instrument was then shut off, cooled to room temperature and restarted (23 APR 22^H44) 4½ hours later That run (starting near 13 1 K Ω or 28°C in Figure III-1) also indicated the highest frequency encountered After another day and a half the curve was back again to the "normal" position

Reference-Frequency (Field Tests)

During actual field line measurements at several locations on Maui, we followed the same procedures as in the laboratory However, a battery-operated, more portable, 1-MHz standard (James Knight Co model FS-1100T), which was checked against the rubidium standard, furnished the reference frequency for the HP counter

The HP counter indications were noted together with the thermistor resistance and battery voltage for comparison The corrections for battery voltage variation (2 9 Hz/volt) were applied before plotting the field data (dots) presented in Figure III-2 In the same figure, the normal laboratory and the cold room/normal curve (see laboratory test) are included for reference During field measurements the ambient temperature was the same as in the laboratory, but the winds (10 to 15 knots) seem to have shifted the curves toward higher thermistor resistance, indicating a modified temperature gradient from the thermistor to the oscillator This results in about 1 x 10^{-7} lower frequency reading at the same thermistor resistance than in the laboratory Also stabilization seems to be reached earlier There is remarkably little spread in the field data, about 5 x 10^{-8} in frequency This indicates that the use of this 'reference curve" and the battery voltage correction yields the frequency well within ± 1 x 10^{-7} It should be pointed out that these field measurements need only the indicated resistance and voltage measurements to stay within ± 1 10^{-7}

Linearity Test

To achieve better accuracy than the specified ± 5 mm part of the instrument, linearity measurements over a basic 10-m interval were performed at different times First, distances along a baseline were taped off very carefully (in the institute basement with metal tapes 3 or 5 m long) The reflectors were then moved either between 10 and 20 m or 20 and 30 m along the baseline in 50-cm intervals, and 20 or more readings were taken at each position Standard deviations of the

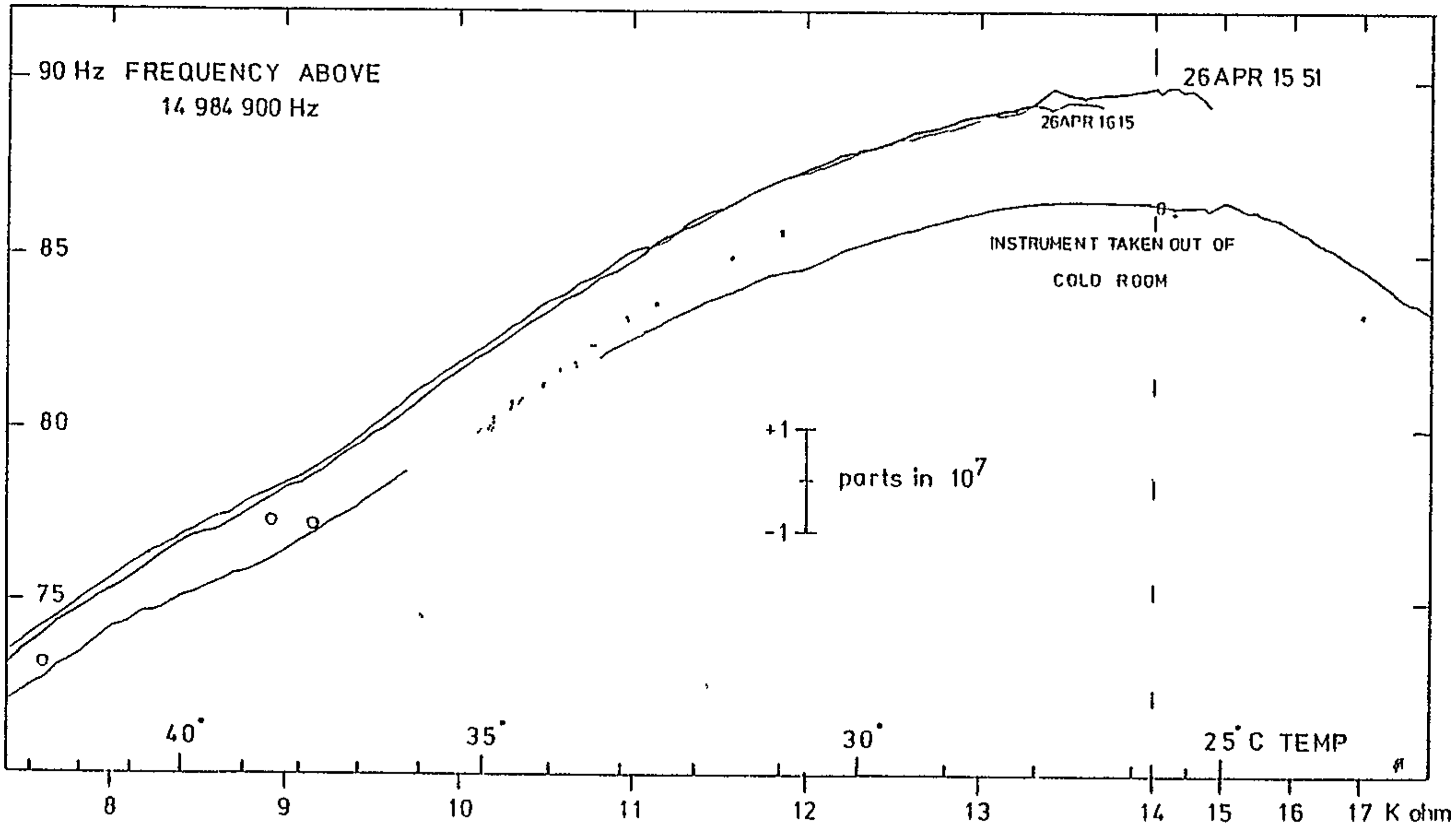
90 Hz FREQUENCY ABOVE
14 984 900 Hz
26APR 15 51
26APR 1615
INSTRUMENT TAKEN OUT OF
COLD ROOM
85
80
75
+1
-1
parts in 10^7
40°
35°
30°
25° C TEMP
8
9
10
11
12
13
14
15
16
17 K ohm

Fig III-2

mean values ranged from a "low" ± 0.20 to a "high" ± 0 40 mm Set up errors in distance between the instrument and the reflector were estimated to be smaller than 2 mm (probably 1 mm) for measurements taken at several months interval and using different metal tapes.

Several problems were encountered At the short distance the variation of the physical location of the return beam on the optical system varies the readout sometimes by as much as 5 mm, everything else being held constant (including the returned signal strength of the beam as measured by the meter on the instrument) Using a corner cube reflector, the beam at these short distances is only 5 to 8 mm in diameter After a series of measurements made in May/June and again in mid-October 1977, it was decided to use only a "dot" reflector, which is composed of small glass beads and returns a wide, diffused beam, that even at the short distances covers a considerably larger area than the instrument's optics The results of the linearity measurements, using a dot reflector (in mid-October) are presented in Figure III-3 (lower curve) where the top graph is as given by the K & E Company

Some variation of the measured lengths also was found when the signal strength varies within the admissible range Usually shorter distances (2 to 3 mm) were indicated at the higher signal level (that is at the right side of the green field of the meter for the external beam (the internal signal strength being held constant in the center of the meter) 2 to 3 mm of the observed scatter in actual field distance measurements on the long lines therefore seems to be attributable to variation in signal strength

We feel therefore that about ± 2 mm is the limit, due to the combined effects of nonlinearity and signal strength variation

Peg Test

The "peg" test determines the instrument offset, that is a constant for a particular instrument This offset is added to the calculated length when a Model 8 geodimeter is used, or dialed in directly for the Rangemaster II, so that the displayed length is already offset corrected For the test a line AC with an intermediate point B is measured along AB, AC and BC resulting in measured lengths AB-K, AC-K and BC-K, where K is the offset

Since $AB + BC = AC$

it follows that

$$(AB - K) + (BC - K) = AC - 2K = (AC - K) - K$$

or

$$K = (AC - K) - (AB - K) - (BC - K)$$

The test was carried out in February at receipt of the Rangemaster II on a 60-m base line in the Institute's basement Using the offset 137 mm determined by the manufacture, the remaining closure error was 0 7 mm The same three test points were also occupied at the same time with a Model 8 geodimeter Two of the measured lengths were within 0 2 mm of the values obtained by the Rangemaster II, the third one was off by 11 0 mm

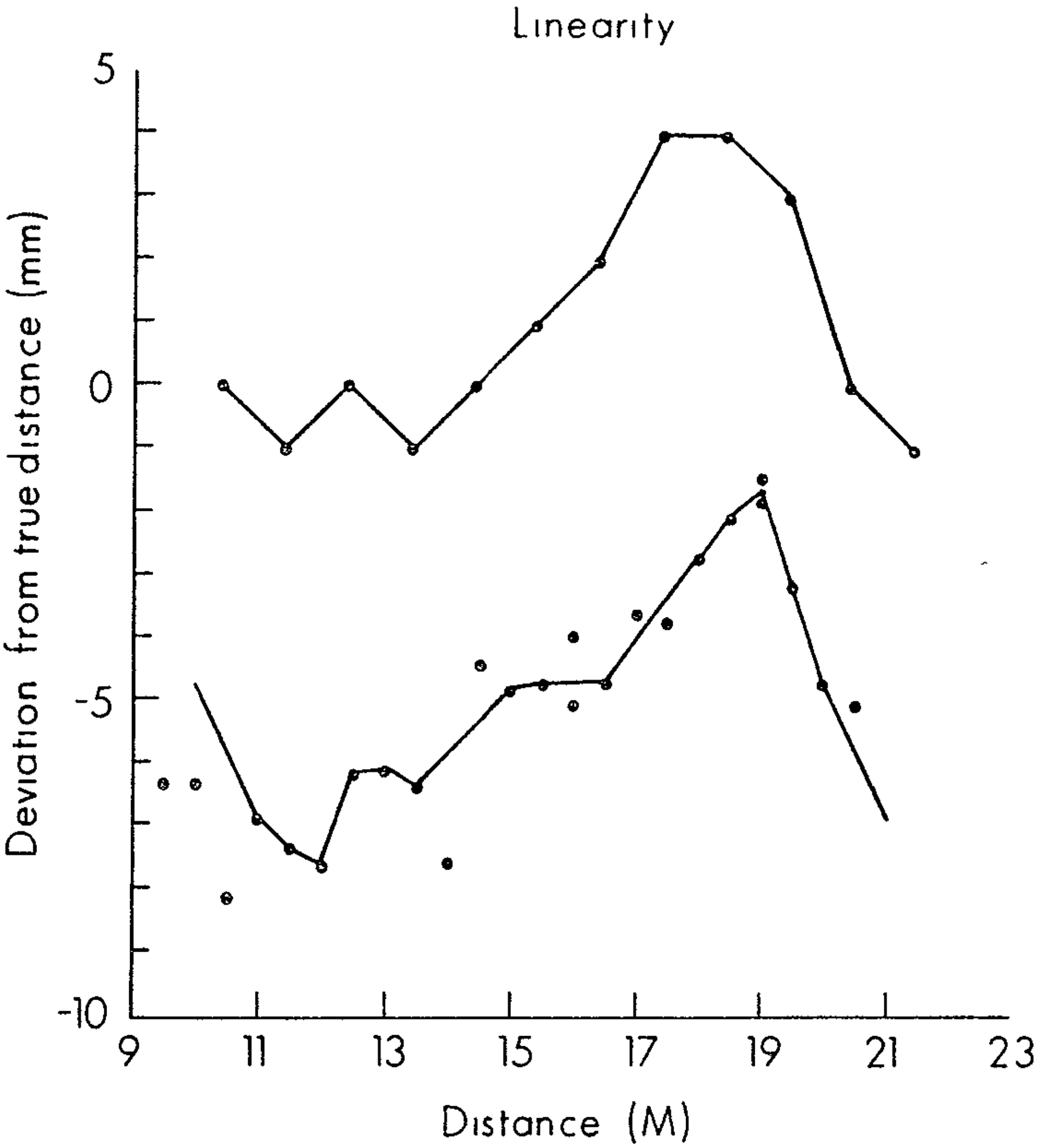
Linearity
Deviation from true distance (mm)
5
0
-5
-10
9
11
13
15
17
19
21
23
Distance (M)

Fig III-3

Barometers

In order to comply with the strict requirements set forth in Chapter I to achieve an ultimate accuracy in the line measurements of the order of a few parts in ten millions, all necessary precautions were taken into consideration. Barometers and psychrometers were calibrated in a proper way to bring them into one common system of data collection.

The barometric pressure readings on the ground were taken with the Negretti and Zambra Model M2236 Digital Barometers at lower altitudes (800-1050 mb) and with the Model M2131/B Digital Barometers at higher altitudes (550-800 mb). The specified accuracy at 20°C is ± 0.4 mb, and is ± 0.7 mb over the range of 5-35°C. Each instrument coming from the factory was provided with the linearity correction table. As a back-up instrument an old Wallace Tiernan aircraft type aneroid barometer was used. It had capability for continuous pointer reading between 60 and 1050 mb. No accuracy figures were available.

By comparing all instruments in a pressure chamber, it should be possible to detect any drift or shift in the calibration or linearity of individual instruments. These comparisons were made by placing two instruments at a time into a small pressure chamber which was pumped down to simulate the range of altitudes encountered in our project. While in the chamber, the knob on the barometer was remotely manipulated by means of a small servo motor attached on each barometer. We found that the linearity correction curve was substantially different when the whole instrument was subjected to the reduced pressure environment, rather than just connecting the pressure to the port fitting.

The available three low-altitude digital barometers were numbered as 1-3, the three high-altitude digital barometers were numbers as 4-6, and the aircraft barometer was assigned the number 8. All low-altitude barometers were compared to the number 1, which in turn was corrected to its factory calibration values. Similarly, the high-altitude barometers were compared to the number 6. For the absolute calibration, number 1 and number 6 digital barometer will be eventually compared to a quartz barometer. The results of the linearity correction tests are given in Table III-1 and in Figure III-4. The tabulated value and curve for number 1 and number 6 are those supplied by the manufacturers.

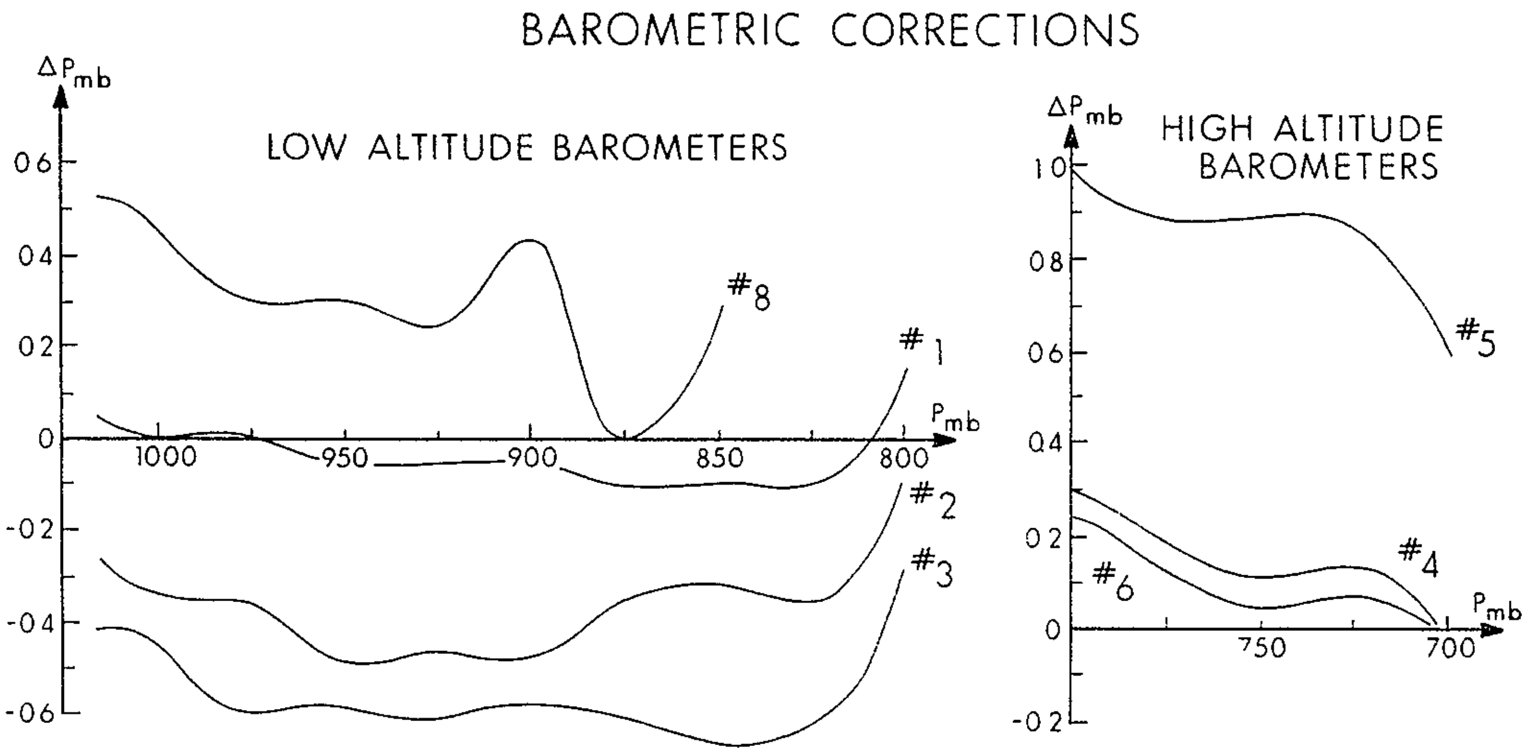
BAROMETRIC CORRECTIONS
LOW ALTITUDE BAROMETERS
ΔP mb
0 6
0 4
0 2
0
-0 2
-0 4
-0 6
1000
950
900
850
800
P mb
#8
#1
#2
#3
HIGH ALTITUDE BAROMETERS
ΔP mb
1 0
0 8
0 6
0 4
0 2
0
-0 2
750
700
P mb
#5
#4
#6

Fig III-4

TABLE III-1

Barometric level in Millibars	Barometric Corrections in Millibars						
	#1	#2	#3	#8	#4	#5	#6
1015	+0 03	-0 27	-0 42	+0 53			
1000	±0 00	-0 35	-0 45	+0 45			
975	±0 00	-0 36	-0 60	+0 30			
950	-0 05	-0 49	-0 58	+0 30			
925	-0 05	-0 46	-0 61	+0 25			
900	-0 05	-0 47	-0 57	+0 45			
875	-0 10	-0 34	-0 60	±0 00			
850	-0 10	-0 31	-0 66	+0 30			
825	-0 10	-0 35	-0 62				
800	+0 15	-0 09	-0 27		+0 30	+0 97	+0 25
775					+0 18	+0 89	+0 13
750					+0 11	+0 90	+0 05
725					+0 14	+0 85	+0 08
700					+0 01	+0 61	+0 00

Bearing in mind the ±0 35-mb maximum allowable error in pressure for ±0 1-ppm range accuracy, it can be seen that the nonlinearity does contribute a significant error Since each instrument stayed at a fixed location while a line was being measured, the linearity correction was entered manually for each line to the data reduction program

Psychrometers

The Model H331 Assman Psychrometers (manufactured by Weathermeasure Corporation) used for temperature and water vapor pressure determinations on the ground were found to contribute errors considerably greater than the 0 1°C maximum allowable error for ±0 1-ppm range accuracy Therefore, ten available thermometers from five psychrometers were taken from their supports and intercompared in water baths of various temperatures with two precision thermometers originally calibrated in 1972 at the Ohio State University (Cushman, 1972)

In the calibration of the OSU thermometers the following formula was used

$$\Delta T = T_{cal} - T_{obs} = c_o + c_1 T_o + c_2 T_o^2 + c_3 T_o^3 \qquad (III\text{-}1)$$

which procedure yielded the following coefficients

Thermometer Serial Number	c_o	c_1	c_2	c_3
06239	0 0134	0 0027	-0 00032	0 000007
06245	0 0244	0 0049	-0 00092	0 000039

These values were determined during several hundred intercomparisons between each of the thermometers and a standard traceable to The National Bureau of Standards It should be noted, however, that these intercomparisons were made only over the temperature range of -5°C to 12°C

To calibrate the University of Hawaii thermometers used in our project, equations of the form

$$T_{comp} = c_o + c_1 T_{obs} \qquad \text{(III-2)}$$

were determined for each thermometer The process was as follows

1 Averaging two values read from each OSU thermometer
2 Correcting these temperatures for the calibration
3 Averaging these values and using this as the temperature of the bath
4 Computing δT for each UH thermometer at this temperature
5 Computing c_o and c_1 by utilizing linear regression to the data
6 Computing some statistics of the regression

The reduced data were fitted with first degree equations and also plotted to see if there was any great indication that a first degree equation was inadequate There was none

The coefficients and related correction curves thus obtained are given in Table III-2 and Figure III-5 where the UH thermometer numbers are provided with dry and wet bulb indications (D, W)

TABLE III-2

Thermometer Serial Number	UH Thermometer Number	c_o	c_1
209	1D	-0 175	1 000
182	1W	-0 014	1 001
51114	2D	-0 187	1 009
51040	2W	-0 023	1 005
339	3D	-0 425	1 008
248	3W	0 153	0 995
51027	4D	0 274	0 995
51130	4W	-0 276	1 016
51011	5D	-0 416	0 983
51150	5W	0 480	0 969
51013	6D	0 062	1 002
51117	6W	-0 399	1 021

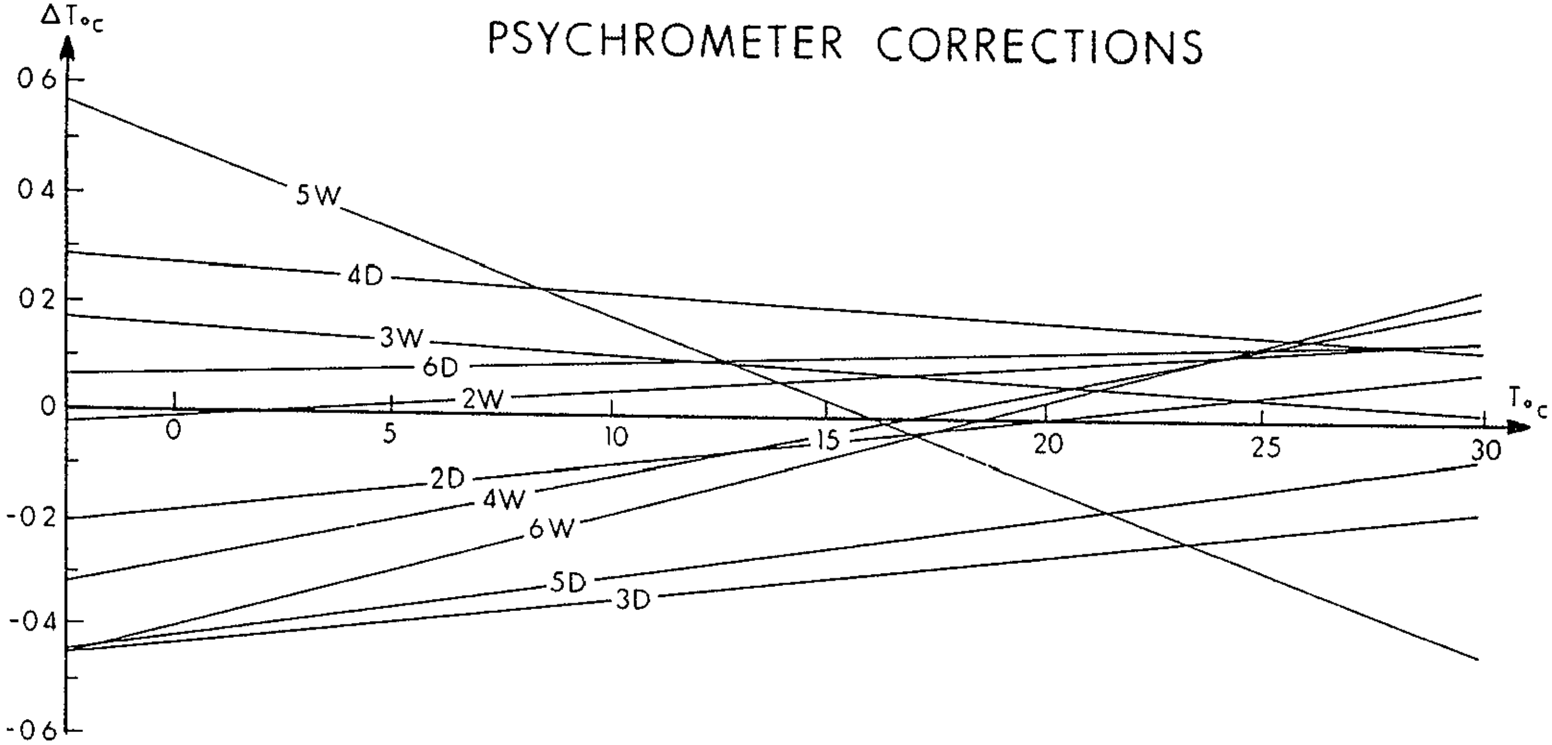
PSYCHROMETER CORRECTIONS
ΔT°c
0 6
0 4
0 2
0
-0 2
-0 4
-0 6
0
5
10
15
20
25
30
T°c
5W
4D
3W
6D
2W
2D
4W
6W
5D
3D

Fig III-5

The observed atmospheric parameters T, P, and e are all dependent on the elevation of the observation point, and thus liable to errors due to errors made in defining that elevation Bearing in mind the allowable errors for the 0 1-ppm accuracy, the following summary can be presented

With a typical temperature lapse rate of about 6°C/km, an error of 0 1°C will occur in about a 17-m change in elevation An error of 0 35 mb in pressure will occur in a 3 1-m change in elevation at sea level, or in a 4 1-m change at an elevation of 3000 m The 2 5-m error in water vapor pressure represents about 10% of the existing sea level water vapor pressure, and 50 to 100% of the typical water vapor pressure at an altitude of 3000 m

Considering the different procedures to determine the observation elevations (at the fixed ground points and in the moving helicopter), the analyses of the maximum allowable errors, along with their equivalents in terms of elevation changes, serve as a realistic approach to the actual field measurements of the atmospheric refractive index

Airborne Instruments

(Digiquartz, thermistor, hygristor)

Measuring atmospheric conditions and flying height from helicopter data poses some special problems The effects of the helicopter itself on the measurements must be carefully determined and compensated for The helicopter "probe" includes a "digiquartz" pressure transducer (barometric pressure and altitude), a thermistor ("dry' temperature) and a hygristor (relative humidity)

Since the FAA would not permit a boom to be attached to the helicopter to place the probe out from under the downwash of the rotor, it was necessary to measure its effects as accurately as possible

First, there are static pressure effects The helicopter is supported by a high-pressure area under the rotor The magnitude of this pressure, as calculated from disk loading for the model helicopter used, amounted to only +1 4 mb Since this is already smaller than the allowable error (for determining the refractive index for 1-ppm range accuracy) this pressure could have simply been subtracted as a constant Actual measurement of the pressure error when hovering just above "ground effect," however, showed that the high pressure from the rotor is being partially offset by the pressure drop caused by aerodynamic flow of the rotor downwash around the body of the aircraft The result is that the apparent discrepancy between a free air measurement and a helicopter measurement when hovering above the ground cushion effect is less than 0 1 mb

When the helicopter is in forward motion, there are two other effects on the pressure measurement One results from the rotor downwash being tilted backwards, rather than straight downwards, resulting in a different flow pattern for the downwash The second effect is the pressure drop at the point where the probe is mounted due to the aerodynamic flow of the air around the body of the helicopter In order to evaluate the effect of forward velocity, we ran several calibration runs at a constant altitude of 50 feet above the open sea, starting from a hover, and increasing to over 100 mph We expected to see a pressure decrease proportional to the square of the airspeed, and a least squares fit to the data showed this to be very nearly true While actually measuring a line, we held the helicopter airspeed as constant as possible, and logged the airspeed along with the atmospheric data The empirical correction for airspeed was added to the computer program, including an air density correction proportional to altitude

There is also an undesirable effect of the helicopter on the temperature measurement The temperature measured by the probe is the temperature of the air pulled down from an unknown height above the helicopter and possibly heated to some unknown degree by the energy from the rotor Since the lapse rate is typically 6°C/km, the allowable error of ±0 1°C in the temperature measurement is equivalent to an elevation difference of 17 m These two effects should produce errors of opposite sign, but the degree to which they may offset each other is not precisely known at this time

The relative humidity is measured by means of a hygristor in the probe Although the hygristor is quite prone to drift, the allowable error in the determination of the water vapor pressure of ±2 5 mb is not difficult to control The response time of the hygristor is only about 2 seconds, and there is no need for supplying moisture to a wet bulb thermistor, making the hygristor quite acceptable for this application

The probe was mounted on one of the struts of the helicopter, below the front left door The static port for the pressure measurement was made in the form of a "T", to make it relatively insensitive to the exact angle of the air flow, and the thermistor and hygristor were mounted inside a small protective plastic tube Since the most critical factor for determining the refractive index (or the refractive number N) from the helicopter atmospheric measurements is its altitude determination, special precautions have been taken These precautions are elevation checks at the line end points with the helicopter flying level with the markers and simultaneously taking pressure reading from the "Digiquartz" pressure transducer The helicopter is directed to that level by radio voice communication from the end point site (See "Helicopter altitude")

IV. REFRACTIVE INDEX

(Individual Points)

Ground Stations

At the sites of the laser, the reflectors (and possibly other ground stations), the psychrometer (wet and dry) temperatures and the digital barometer pressure are read at (equally spaced) time intervals together with the time These raw data appear in the computer printout under "Atmospheric data taken at " where gives the location name The observed values are first corrected according to instrument calibrations Using corrected values the water vapor pressure e is calculated

$$e = 269782133 \cdot \exp\left(\frac{-4271\ 071252}{TW + 242\ 625445}\right) \qquad \text{(IV-1)}$$

$$- 0\ 00066 \cdot (1 + 0\ 00115\ TW) \cdot P \cdot (TD - TW)$$

where TW = wet bulb temperature

TD = dry bulb temperature

P = pressure

The first term of Eq. (IV-1) is the saturation pressure of water vapor obtained from a least squares fit to the Smithsonian psychrometric tables from 0° to 25°C

Finally the refractive number N is obtained from (Laurila, 1976, p 132)

$$N = \frac{300\ 2 \cdot P - 41\ 8e}{3\ 709(TD + 273\ 15)} \qquad \text{(IV-2)}$$

The results of the calculations and their mean values are printed out under the heading "Reduced Atmospheric Data " In this "Reduced Atmospheric Data" block, only those raw data from the preceding block have been reduced, that are between the *sign The mean value of N for the ground station is used together with the mean value of the other ground station and from the helicopter data to determine the mean refractive index along the laser beam (see Appendix I)

Since the long lines are only measured during the night, systematic changes of N at the terminal ground points are small, if any, and are averaged in the described procedures during the time it takes the helicopter to fly the line (about one half of an hour) However, the helicopter flies line AB first from A to B and then turns to fly from B to A Measurements taken during flight time from A to B are treated as one line measurement, and the return flight measurements from B to A are treated as a second independent measurement of the same line Therefore time variation of atmospheric conditions are reflected (a) in the mean values of N at the ground points and the mean values for the total line, (b) in the frequency corrected direct range readings of the laser

Since the frequency corrected ranges of the laser ($\underline{D}$ in Eq V-1) are inversely proportional to the mean refractive index $\bar{n}$ along the line, the comparison of the mean (frequency corrected) of the ranges D of the forward and the mean of the D's of the return flight is the most stringent test on the mean $\bar{n} = (1 + \bar{N} \cdot 10^{-6})$ obtained for each of the two flights The output plots of the various data have been partially included to detect such trends (see figures in Appendix I)

Helicopter Line Measurements

Before takeoff and after the forward and return flights along a line, the helicopter instrument values (Digiquartz frequency, hygristor and thermistor resistance) are compared on the ground to those obtained from the digital barometer and dry and wet bulb temperatures These data appear in the computer outputs under "Initial (or Final) Calibration of the Helicopter Hygristor at Airport"

From measurements taken during the flight, temperature, pressure and water vapor pressure are determined

Temperature (from thermistor resistance)

$$T(^\circ K) = \frac{1}{10^{-6} \cdot (3297\ 71 + 474\ 579 \ln RTH1 + 5\ 54285 (\ln RTH1)^3)} \qquad \text{(IV-3)}$$

T = temperature (degrees Kelvin)

RTH1 = RTH/13 637

RTH = thermistor resistance (k ohm)

13 637 = calibration resistance at 25°C

Pressure (from Digiquartz frequency)

$$\text{pres} = P + \text{velocity correction} \qquad \text{(IV-4)}$$

$$P = [10592\ 79\ (1 - \frac{Freq}{F}) - 5890\ 86\ (1 - \frac{Freq}{F})^2\ ]\text{mb} \qquad \text{(IV-5)}$$

Freq = Digiquartz frequency (Hz)

F = zero pressure frequency, calculated for each line by comparison with ground instruments, written out in the helicopter calibration section above the uncorrected data

$$\text{Velocity correction} = P\ (\frac{0\ 0009604\ V^2}{1012} - 0\ 0000102\ V)\ \text{mb} \qquad \text{(IV-6)}$$

V = helicopter air speed (mph)

Water vapor pressure (from hygristor resistance)

$$e = ESAT \cdot \%RH/100 \qquad \text{(IV-7)}$$

= water vapor pressure (mb)

$$ESAT = 269782133 \exp (-4271\ 071252/(T + 242\ 626)) \qquad \text{(IV-8)}$$

= least square fit to the Smithsonian psychrometric tables from 0° to 25°C, using "dry bulb temperature"

T = temperature (deg C) (from thermistor)

$$\%RH = 31\ 71 + 69\ 28\ R - 18\ 58\ R^2$$

= least square fit to the published per cent relative humidity curve

R = log (CALIB   CRES)

$CALIB = 1 - (1 - H)(1 - T/25)$

= linearly interpolated temperature correction to the 25°C curve

$H = 0.98599 - 0.36991 \log CRES + 0.11159 (\log CRES)^2$

= least squares fit to the temperature correction curves from 0° to 25°C

CRES = RHYG/R33 = normalized hygristor resistance

RHYG = Hygristor resistance (k ohm)

R33 = Hygristor resistance at 33% relative humidity and 25°C. R33 is determined for each line and printed out with the helicopter calibration data

Refractive Number N

The refractive number N is calculated by the same formula (IV-2) as for the ground stations using Pres (IV-4), the velocity corrected pressure, e(IV-7) the water vapor pressure and T(IV-3) the temperature determined from the thermistor readings The refractive number N thus determined is assigned to the helicopter altitude as calculated in the next paragraph

Helicopter Altitude ALT

The helicopter altitude ALT_i at point number i is determined in two distinct steps

The first is the use of linearized integration of a barometric height formula, starting at the ground station from which the helicopter flies away This results in barometrically determined height increments $H_\ell - H_{\ell-1}$

The helicopter barometric height is therefore given by

$$H_i = ALT_o + \sum_{\ell=1}^{i} (H_\ell - H_{\ell-1}) \qquad i = 1,2, \ldots E \qquad \text{(IV-9)}$$

where $H_o = ALT_o$ is the known elevation of the starting ground station and H_E is the resulting barometric height of the end marker elevation, which in general is different from ALT_E, the known end marker elevation

The second step consists of multiplying the barometric height H_i by an adjustment factor HC, so that the barometric height difference of the end points is made equal to the known difference $(ALT_E - ALT_o)$, that is we set

$$HC (H_E - H_o) = ALT_E - ALT_o \qquad \text{(IV-10)}$$

Note that on the return flight the previous end point becomes the new starting point for the integration and that the new end point is the old starting ground station and included in the barometric height calculation The barometric helicopter height H_i is calculated from the velocity corrected pressure P_i (previously called Pres), the water vapor pressure e_i and temperature T_i from 'Humphrey's formula" (Humphreys, 1940)

$$H_\ell - H_{\ell-1} = 18.4 \log \frac{P_{\ell-1}}{P_\ell} \cdot [1 + 0.00367(T_{\ell-1} + T_\ell)/2] \cdot \qquad \text{(IV-11)}$$

$$\cdot [1 + 0.378 \cdot (\frac{e_{\ell-1}}{P_{\ell-1}} + \frac{e_\ell}{P_\ell}) \cdot \tfrac{1}{2}] \cdot 1.001958 \, (1 + \frac{2H_{\ell-1}}{6371})$$

where pressures are measured in mbar, temperature in degrees C, and heights in km. The final helicopter altitude thus becomes

$$ALT_i = HC \cdot H_i \qquad \text{(IV-12)}$$

and is printed out in the section "Reduced Helicopter Atmospheric Data" in the column "Adjusted ALT (KM)" and the adjustment factor HC appears at the end of that same section as "Multiplication Constant to Humphreys' Formula - ". The "ALT (km)" column in the uncorrected helicopter line data is obtained from readings of the built-in helicopter altimeter (see Appendix I).

The values of the refractive numbers N_i associated with the heights ALT_i are the ones used in the next chapter to determine the mean refractive index $\bar{n}$ along the line.

Discussion

As pointed out earlier (page 25) one would like to see the altitude determination within ± 3 m at sea level and ± 4 m at some 3000 m. Since a number of empirically determined corrections affect the values of ALT some measure of confidence in the calculated values is required, but no direct statistics are available. However, since each line is flown in the forward and return direction (up and down for brevity) two independently determined adjustment factors HC are available for each line and can be compared. The difference between the "up" HC and the "down" HC thus provides a convenient measure of closure. A difference of 0.0012 in HC, for example when taken over a 1-km elevation difference gives a difference of 1.2 meters at one of the end points. Since the end points have been adjusted to the known marker elevation, half of that difference or 0.6 m at most could be expected at the mid point of the line.

It can be seen that on one of the most difficult lines (through the atmospheric inversion) from Pier to ARPA on June 20, 1977 the two HC values are (Appendix I) 0.996377 and 0.994761 that is a difference of 0.00162. When this difference is multiplied by the known elevation difference of 3033.58 - 2.28 = 3031.30 m, a discrepancy of 5.06 m remains. Since the end points have been adjusted, half of that amount or 2.53-m error could be expected at mid altitude. This value is within the required altitude tolerances.

V MEAN REFRACTIVE INDEX AND FINAL MARKER-TO-MARKER CHORD DISTANCE

Uncorrected "Range" data (D_m) are those directly read from the Rangemaster II display, which include the dialed-in offset (137 mm) A number of Range values are obtained with time Since oscillator drift has been a problem, the individual D_m's are first frequency corrected

$$D = D_m \cdot 14\ 984\ 980/F \qquad \text{(V-I)}$$

where F is either the directly measured frequency, or calculated as a function of supply battery voltage (BV (volts)) and the resistance of the thermistor (RTH (k ohm)) placed on the reference oscillator

$$F = 14\ 984\ 980 + 2\ 7\ (BV - 12\ 5) - 84\ 3 + 12\ 73\ RTH$$
$$- 0\ 434524\ RTH^2 \qquad \text{(V-2)}$$

Following the frequency correction, individual length Ranges (D) are reduced from the lengths between the instrument and reflector on their tripods to the corresponding lengths between the benchmarks (D_B)

$$D_B = \sqrt{D^2 - A} + CORR \qquad \text{(V-3)}$$

$$A = 2(1 - \cos(\arctan D/R))\ (R + LOEL)\ (RH + IH)$$
$$+ 2(RH - IH \cos(\arctan D/R))\ (HIEL - LOEL) \qquad \text{(V-4)}$$

$$CORR = ECC + ECD + OFF + LIN \qquad \text{(V-5)}$$

where

R = earth radius (6371 km)
LOEL = elevation of lower marker
HIEL = elevation of upper marker
IH = height of laser (or reflector) above lower marker
RH = height of reflector (or laser) above upper marker
ECC = eccentricity (setup offset over marker) of laser
ECD = eccentricity (setup offset over marker) of reflector
OFF = reflector offset correction (-40 mm for our corner cubes)
LIN = linearity correction of laser (in the basic 10-m interval)

The marker-to-marker Ranges D_B appear in the computer printouts (Appendix I) under the heading "Reduced Range data in meters" and in the column "Frequency corrected " The marker-to-marker Ranges D_B are then corrected to the marker-to-marker laser beam length D_A

$$D_A = D_B \quad n_1/\bar{n} \qquad \text{(V-6)}$$

where

n_i = refractive index assumed by the instrument (1 00030984)

$\bar{n}$ = mean refractive index of the line

$$\bar{n} = 1 + \frac{1}{\mathrm{HIEL} - \mathrm{LOEL}} \sum_{i=1} \frac{N_i + N_{i-1}}{2} (\mathrm{ALT}_i - \mathrm{ALT}_{i-1}) \cdot 10^{-6} \qquad \text{(V-7)}$$

N_i = refractive number at elevation H_i along the beam, each mean refractive number $(N_i + N_{i-1})/2$ is weighted with its relative section length $(\mathrm{ALT}_i - \mathrm{ALT}_{i-1})/(\mathrm{HIEL} - \mathrm{LOEL})$

The numerical integration to obtain the mean refractive index $\bar{n}$ was preferred over the "classical" polynomial model (as a function of the height H) approach because of the very sharp variation of n over short height intervals (see Figures in Appendix I) due to the inversion layer that occurs near 1500-m elevation (see section XIII on Alternate Mathematical Methods)

The marker-to-marker curved beam length (D_A) is further reduced to the straight line marker-to-marker "Reduced Range" D_C by the amount of the "beam curvature correction" ΔD_A (Laurila, 1976, p 120)

$$D_C = D_A - \Delta D_A \qquad \text{(V-8)}$$

$$\Delta D_A = \frac{k(2-k) \cdot D^3_A}{24R^2} \qquad \text{(V-9)}$$

The value of k is obtained under the assumption of a linear gradient for the refractive index n between the two end points of the line

$$k = \frac{n_1 - n_L}{H_L - H_1} \quad R \qquad \text{(V-10)}$$

where

n = refractive index

H = elevation

R = earth radius

1 refers to the lower point and L to the higher point of the line

The values of the straight line marker-to-marker reduced Range D_C appear toward the end of the computer outputs for an individual line under the heading "Reduced Range data in meters" in the column "Reduced Range " The average of these individual Reduced Ranges appears as "mean corrected line length" together with the standard deviation of an individual "Reduced Range" and the "standard deviation of the mean" σ_M which could be considered to be the standard deviation of the line length In the computer printout also appears the mean refractive number N that served to calculate the curved marker-to-marker beam length (D_A)

It should be clearly noted that σ_M reflects only the variations of D, the frequency corrected direct Range readings of the laser These variations are partially due to instrument noise, but also include any changes in atmospheric conditions during the time span data were taken The variation (σ_M) certainly does not reflect any (possibly systematic) errors in the individual determinations of the refractive index n along a line integrated to obtain the mean refractive index $\bar{n}$ Errors in the beam curvature correction are negligible since this correction is small As an example, in the Pier 2 to ARPA line with an elevation difference of 3 km and a distance of 30 km the correction is only around 8 to 9 mm

VI PLOTTING OF DATA

Plotting the unreduced data aids in eliminating either erroneous readings taken in the field or mistakes in transferring the data to the computer input format Second, a graphic representation of the reduced data aides in interpreting the observations Last, the plots enable the analysis of field procedure. For example, the plots of wet bulb temperature indicate that sharp jumps in the temperature of about one degree Centigrade occur immediately after winding the fan and wetting the wet bulb of the psychrometers The plots indicate that a two-minute delay in taking readings after this procedure would eliminate the sharp peaks in these data and thus reduce the standard deviation of the wet bulb temperature readings

DATA 1 is written in FORTRAN IV computer language and is executed on the Harris Corporation VULCAN computer system Subroutines MPLOT, GNPLOT, AAXS, and TAXIS of the DATA 1 computer program (see computer printout) use XYNETICS plotting subroutines to write plotting instructions onto magnetic tape The tape is input to the XYNETICS 1100 automated drafting system which plots the data The XYNETICS 1100 has a plotting accuracy of better than 0 03 mm

In writing the plotting program a generalized plotting subprogram has been developed which has two distinctive features First, the subprogram plots either decimal or time series data (the Y-axis can plot only decimal data, while the x-axis can plot either decimal or time series data) The time-axis annotation interval is set by the subprogram according to the time length of the data The time interval can be as small as ten minutes and as large as a month in length Second, in the case of decimal data, annotation values of only the significant part of the plot values are determined and annotated on the axes by the subprogram The annotation values are round numbers which allow quick and easy observation of the numerical changes in the data The non-significant part of the data is a number written out above each plot The plotting subprogram consists of subroutines MPLOT, GNPLOT, AAXS and TAXIS which accomplish the actions explained above The main program (Appendix II, III) calls MPLOT and MPLOT calls the other subroutines

VII REDUCTION OF SPATIAL CHORD DISTANCES ONTO TRANSVERSE MERCATOR CONFORMAL PLANE

This reduction is necessary to allow comparison between new laser distances and old U S Coast and Geodetic Survey or Hawaiian Government Survey distances determined by triangulation method decades or even a century ago It is also needed in conditional adjustment of quadrilaterals with diagonals and/or a center point (Section VIII) to determine the strength of figures composed of measured lines reduced onto a common plane

Reduction

The process of the reduction consists of two steps 1) reduction of the spatial chord distance of the measured laser line to an ellipsoidal arc distance, and 2) reduction of the ellipsoidal arc distance onto the Transverse Mercator conformal plane The ellipsoid used in computations is that of Clarke 1866 with the following parameters

$a = 6,378,206\ 4$ m	Semimajor axis	(VII-1)
$e^2 = 0\ 006768658$	Eccentricity square	

The Transverse Mercator projection used as basis for the plane coordinates of the HGS and HTS has the following specifications, at the Zone 2 on the island of Maui

CM = 156°40'00"W	Central Meridian,	(VII-2)
SR = 1 30,000	Scale reduction at the central meridian,	
SF = 0 999966667	Scale factor at the central meridian	

The ellipsoidal arc distance d_A is obtained as follows (Wong, 1949, Laurila, 1960, 1976)

$$d_A = \left[\frac{12R^2(D_C{}^2 - (h_1 - h_2)^2)}{12\ (R + h_2)(R + h_1) - (D_C{}^2 - (h_2 - h_1)^2)}\right]^{\frac{1}{2}} \qquad \text{(VII-3)}$$

with

$$R = \frac{MN}{M\sin^2 A + N\cos^2 A} \qquad \text{(VII-4)}$$

$$M = \frac{a(1 - e^2)}{(1 - e^2\sin^2\phi)^{3/2}} \qquad \text{(VII-5)}$$

$$N = \frac{a}{(1 - e^2\sin^2\phi)^{1/2}} \qquad \text{(VII-6)}$$

where

D_C = spacial chord distance (Eq V-8)

h_1, h_2 = elevation of the terminal markers of the line

R = radius of curvature of the ellipsoid at the azimuth A of the line

A = azimuth of line (clockwise from the map north)

M = radius of curvature of the meridian

N = radius of curvature in the prime vertical

ϕ = mean latitude of the terminal markers of the line

Finally the ellipsoidal arc distance, d_A, is reduced onto the Transverse Mercator plane by the following formula

$$d_M = d_A \left(0\ 999966667 + \frac{X_1^2 + X_1X_2 + X_2^2}{6R^2}\right) \qquad \text{(VII-7)}$$

where $X_1 + X_2$ are the linear distances from the terminals of the line to the central meridian determined as explained in the following section

Accuracy

The errors introduced in the process of reduction of Eqs (VII-3)-(VII-7) are primarily caused by parameters to be measured or computed from existing data (maps), while the mathematics involved is rigorous to a high degree The total cumulative error is not a constant over a finite area such as the island of Maui, but is rather a function of several variable parameters The parameters affecting the accuracy of the total reduction are

-- length of line

-- elevation difference of the terminals of the line

-- latitudes of the terminals of the line

-- azimuth of the line

-- distances of the terminals of the line from the central meridian

-- curvature radius of the ellipsoid along the vertical projection of the line

To illustrate the magnitude of errors of reductions in a typical long line, line #4 from Luke to ARPA is analyzed The parameters of this line given in approximations sufficient for the analysis are

-- length of the line	$D = 31$ km	
-- elevation difference	$\Delta h = 3$ km	
-- mean latitude	$\phi = 21°$	
-- azimuth (clockwise from the map north)	$A = 127°$	(VII-8)
-- terminal distances from the central meridian	$X_1 = 16\ 9$ km (Luke) $X_2 = 41\ 9$ km (ARPA)	
-- curvature radius	$R = 6367$ km	

The cumulative standard error of d_M in Eq (VII-7) is obviously the total differential of the equation with terms added quadratically This is a valid statement because the measured quantities and thus their errors are mutually independent

The error in d_A is a function of errors in R, h_1 and h_2 Errors in marker elevations h_1 and h_2 are treated separately later in the text The error in R is composed of two sources--from the error made in determining the mean latitude ϕ and from the error made in determining the azimuth A

The latitudes of the terminal points can be directly obtained from the U S Coast and Geodetic Survey Form 28 BT if the terminal markers are those established by USCGS or HGS Otherwise, they are measured from 1 24,000 quadrangle topographic maps The standard error of the measurements can be assumed as $\sigma_\phi = \pm 0\ '2$ which yields standard errors in N and M as follows

$$\sigma_N = \pm\ 0\ 001 \text{ km}$$
$$\sigma_M = \pm\ 0\ 002 \text{ km} \qquad \text{(VII-9)}$$

The azimuth of the line can be directly obtained from the U S Coast and Geodetic Survey Form 769 under the condition stated above Otherwise it is determined by coordinates measured from the topographic map The standard error of the measured azimuth can be assumed as $\sigma_A = \pm 0\ °2$ Application of standard errors $\sigma_N, \sigma_M, \sigma_A$ into Eq (VII-4) yields $\sigma_R = \pm 0\ 09$ km This, in turn, when placed into Eq (VII-3) introduces the standard error in d_A

$$\sigma_{d_A} = \pm 0\ 3 \text{ mm} \qquad \text{(VII-10)}$$

The error in the reduction of the ellipsoidal arc distance onto the Transverse Mercator plane is composed of errors made in determination of X_1 and X_2 in Eq (VII-7) These values can be obtained with sufficient accuracy directly from the U S Coast and Geodetic Survey Form 769, if available, as the X-coordinates of the terminal points Otherwise, they are determined by measurements from the topographic map By the estimate $\sigma_{X_1} = \sigma_{X_2} = \sigma_X = \pm 0\ 025$ km, the standard error of the K-factor (second term in the brackets of Eq (VII-7)) will be in the sample line Luke-ARPA

$$\sigma_K = \pm 1\ 3 \times 10^{-8} \qquad \text{(VII-11)}$$

Finally, the application of σ_{d_A} and σ_K into Eq. (VII-7) yields the total cumulative error of

$$\sigma_{d_M} = \pm 0\ 5 \text{ mm} \qquad \text{(VII-12)}$$

While the cumulative standard error σ_{d_M} composed of the errors in the determination of the parameters σ_ϕ, σ_A, σ_{X_1} and σ_{X_2} is very small and insignificant, the standard error in d_M caused by errors in elevations h_1 and h_2 of the line terminals is very dominant With a slight approximation, irrelevant to this analysis, Eq (VII-3) can be differentiated into the familiar "height-base" ratio form as follows

$$\sigma_{d_A} = \pm \frac{\Delta h}{D} (\sigma_{h_1}{}^2 + \sigma_{h_2}{}^2)^{\frac{1}{2}} \qquad \text{(VII-13)}$$

where Δh is the elevation difference between the terminal points, D is the distance, σ_{h_1} and σ_{h_2} are the standard errors of the elevations Since in practice σ_{h_1} and $\sigma_{h_2} = \sigma_h$, Eq (VII-13) can be written

$$\sigma_{d_A} = \pm \frac{\Delta h}{D} \cdot \sqrt{2} \cdot \sigma_h \tag{VII-14}$$

At the present the elevations of all terminal points, excluding Pier 2, are obtained from old vertical angle measurements or third order leveling and are given with an assumed accuracy of ± 0 1 m This value when substituted into Eq (VII-14) and applied to the sample line Luke-ARPA yields

$$\sigma_{d_A} = \pm\ 13\ 7\ \text{mm} \tag{VII-15}$$

When the first order leveling will be available with an assumed accuracy of about ± 1 cm, the corresponding standard error σ_{d_A} in this sample line will be about ± 1 4 mm

The derivation of Eq (VII-3) utilizes some series approximations However, their total effect in the 31-km sample line is only ± 0 4 mm, or $1\ 3 \times 10^{-8}$, which proportional error diminishes rapidly in shorter lines

VIII. CONDITIONAL ADJUSTMENT ON THE TRANSVERSE MERCATOR CONFORMAL PLANE

An assessment of possible errors on some measured lines can be obtained, independent of errors discussed already in Chapters III, IV, V and VII, based on examination of geometrical figures (composed of a number of lines) that are overdetermined For "simplicity" this is done in a plane (rather than in three dimensions) Errors in reducing the chord lengths onto a plane have been discussed in the preceding Chapter (VII)

For those readers who are not fully familiar with the least squares conditional adjustment, especially applied to line measurements, in the following we have slightly amplified the narrative beyond that necessary to present essential bare facts In this attempt we are following the text by Hirvonen (1971, Chapter 7)

In a plane a quadrilateral is fully determined by five elements which can be lines, angles or a combination of both As an example four sides and a diagonal determine the quadrilateral If the four sides and two diagonals are measured (with errors) all line lengths can be adjusted to satisfy all geometrically imposed relations or conditions Since in the example (four sides, two diagonals) there is one element of overdetermination, one "condition equation" has to be found (from relations imposed by the geometry) There is an infinite number of line length corrections that satisfy the geometrical constraints Therefore, one particular type has to be chosen The choice is made by requiring that the sum of the (weighted) length corrections squared is a minimum, resulting in a uniquely determined solution for which the length corrections give a measure of the errors in the measured line lengths

On the island of Maui we have two overdetermined figures The figure in the Hana area is a quadrilateral with two diagonals The second very elongated figure stretches from the Kahului area (Pier, Luke) to the summit of Haleakala (Puu Nianiau, 4RP4) and has two diagonals and four additional lines from an inner point (Kikalapuu) to the corners (see Fig VIII-1) This last figure is thus three times overdetermined, therefore, requiring three condition equations for adjustment, resulting in additional strength of the figure determination This additional strength is important since the figure connects the LURE observatory on Haleakala to stations in West Maui, another land mass, in a direction almost perpendicular to the Molokai fracture zone, a direction in which movement with time might be suspected

For this type of conditional adjustment we followed the method presented by Hirvonen (1971, p 91) to determine the coefficients of the corrections

Quadrilateral

(measured 4 sides, 2 diagonals)

When the four sides and the two diagonals are measured, there is one overdetermination Let us designate the four corner angles (counterclockwise, Fig VIII-1) by A, B, C, D corresponding to the four <u>measured</u> sides AB, BC, CD, DA and two diagonals AC and BD The angles are given by the cosine law in corresponding triangles as

$$
\begin{aligned}
A &= \text{arc cos}\ \frac{AD^2 + AB^2 - DB^2}{2 \cdot DA \cdot AB} \\
C &= \text{arc cos}\ \frac{CB^2 + CD^2 - DB^2}{2 \cdot CB \cdot CD} \\
B &= \text{arc cos}\ \frac{AB^2 + BC^2 - AC^2}{2 \cdot AB \cdot BC} \\
D &= \text{arc cos}\ \frac{CD^2 + AD^2 - AC^2}{2 \cdot CD \cdot AD}
\end{aligned}
\qquad \text{(VIII-1)}
$$

and are functions of the different line lengths only The obvious condition, therefore, is that after the (least squares) adjustment of each line the sum of the corner angles adds up to 360° Since the line lengths are in error, the sum of the angles from Eq (VIII-1) results in a "measured" closure error ω

$$A + B + C + D - 360 = \omega$$

or (VIII-2)

$$F(AB,\ BC,\ CD,\ DA,\ AC,\ BD) = \omega$$

which is reduced to zero after the adjustments δ_{AB}, etc of the individual lines

$$F(AB + \delta_{AB},\quad ,\ BD + \delta_{BD}) = 0 \qquad \text{(VIII-3)}$$

Developing F of (VIII-3) into a Taylor series around (AB, ,BD) and breaking off at the first term (using $F = F(AB,\quad ,BD)$

$$F(AB + \delta_{AB},\quad ,BD + \delta_{BD}) = 0$$

$$F + \frac{\partial F}{\partial AB}\,\delta_{AB} + \frac{\partial F}{\partial BC}\,\delta_{BC} + \frac{\partial F}{\partial CD}\,\delta_{CD} + \frac{\partial F}{\partial DA}\,\delta_{DA} + \frac{\partial F}{\partial AC}\,\delta_{AC} + \frac{\partial F}{\partial BD}\,\delta_{BD} = 0 \qquad \text{(VIII-4)}$$

In this equation the partial derivatives are calculated from Eqs (VIII-2) and (VIII-1) and are constant values obtained from the length measurements The closure error, $F = \omega$ also is a value obtained through (VIII-2) (using (VIII-1)) and the measured lengths The δ's are determined in such a way that the sum of their weighted squares is a minimum

Using for further discussion a_i for the partial derivatives, and δ_i for the line length adjustments ($i = 1,2,\quad 6$) in the same order as in (VIII-4) and remembering that $F = \omega$ (VIII-2) (VIII-4) becomes the condition equation for the line adjustments δ_i

$$F(AB + \delta_1,\quad ,\ BD + \delta_6) = \omega + \Sigma\, a_i\, \delta_i = 0 \qquad \text{(VIII-4a)}$$

In the nomenclature of geodesists the partial derivatives are designated $-1/k_{xy}$, where xy gives the line with respect to which the differentiation has been taken The k's represent different normals from angles to sides in the figure (see Hirvonen, 1971, p 91), a fact that plays no importance in the mathematical development, but shows more or less directly in Eq (VIII-4) how much of a relative importance each line adjustment plays to reduce the closure error to zero As an example let's take

$$\frac{-1}{k_{AB}} = \frac{\partial F}{\partial AB}$$

for line AB, where k_{AB} is the normal from the intersection of the diagonals to the line AB In the very elongated quadrilateral spanning Kahului to Haleakala, the short normals are associated with the long lines and these long lines will therefore be adjusted by larger amounts, whereas the short lines (with long normals k and small 1/k's) will play a much smaller role in the adjustment (in addition to the weight that is attached to the measurements of the lines) We now return to the mathematical development to determine the line length corrections δ_i

In addition to Eq VIII-4 or 4a (reducing the closure error to zero) the δ_i's could be the weighted least squares solution, that is the sum of their weighted squares should be minimum

Since the two conditions are independent of each other, any linear combination of the two (for the same variables δ_i) will lead to the same result If we designate by p_i the weight to be attached to the square of line length #i, the function

$$S = \tfrac{1}{2} \cdot \sum_{i=1}^{6} p_i \delta_i \delta_i + K_1 \left(\omega + \sum_{i=1}^{6} a_i \delta_i\right) \qquad \text{(VIII-5)}$$

is minimized by setting the partial derivatives of S with respect to the variables δ_i equal to zero

$$\frac{\partial S}{\partial \delta_j} = p_j \delta_j + K_1 a_j = 0$$

or

$$\delta_j = - \frac{K_1 a_j}{p_j} \qquad j = 1,2, \quad 6 \qquad \text{(VIII-6)}$$

Since the δ_j have to satisfy (VIII-4a) to reduce the closure error to zero substituting δ_j from (VIII-6) into (VIII-4a) determines the "condition correlate" K_1

$$\omega + \sum_{i=1}^{6} a_i \delta_i = \omega - \sum_{i=1}^{6} K_1 \frac{a_i^2}{p_i} = 0$$

or

$$K_1 = \frac{\omega}{\Sigma \frac{a_i^2}{p_i}} \qquad \text{(VIII-7)}$$

Since on the right hand side, ω of Eq VIII-7 and the a_i's are constants determined from the measured line lengths and the weights p_i for each line are determined from physical considerations, substituting K_1 from VIII-7 to VIII-6 gives the line length adjustments

$$\delta_j = -\frac{a_j}{p_j} \cdot \frac{\omega}{\Sigma \frac{a_i^2}{p_i}} \qquad \text{(VIII-8)}$$

One measure of the error involved in this total adjustment is the standard error of unit weight (Hirvonen, 1971, Eq. (7.14))

$$\sigma = \sqrt{\frac{\Sigma p_i \delta_i^{\,2}}{r}} \qquad \text{(VIII-9)}$$

where r is the number of condition equation, r = 1 in this case. The last equation can be reduced by using Eqs. (VIII-8) and (VIII-7) to

$$\sigma = \sqrt{\frac{\omega \cdot K_1}{r}} \qquad \text{(VIII-10)}$$

Quadrilateral

(Measured: 4 sides, 2 diagonals, 4 lines from one interior point to the corners)

In this case a total of n = 10 lines are measured. Since the number of lines required to fix the geometrical relation between the 5 points is u = 7, the number of independent conditions for adjustment is found to be

$$r = n - u = 3$$

The geometrical figure of the quadrilateral is fixed by the four outside lines and one diagonal (say AC, see Fig. VIII-1). The position of the interior point E is then fixed by two lines from the corners (say AE and DE). Adding then the diagonal BD requires one condition for adjustment. Adding further the line BE requires an additional condition, and adding line CE calls for a third condition. Using each time the new line in the condition equation adds an element not previously used and thus makes the successive condition equations independent of each other, and together with the minimization of the sum of the (weighted) squares of the line legnth corrections allows a unique solution.

In addition to the angles A, B, C, D in Eq. (VIII-1) the following angles are required for the new condition equations

For ω_2

$$AEC = \arccos \frac{AE^2 + CE^2 - AC^2}{2\,AE \cdot CE}$$

$$CED = \arccos \frac{DE^2 + CE^2 - CD^2}{2\,DE \cdot CE}$$

$$DEA = \arccos \frac{DE^2 + AE^2 - AD^2}{2\,DE \cdot AE}$$

For ω_3

$$BED = \arccos \frac{BE^2 + DE^2 - BD^2}{2\,BE \cdot DE}$$

$$CED = \qquad \text{(VIII-11)}$$

$$BEC = \arccos \frac{BE^2 + CE^2 - BC^2}{2\,BE \cdot CE}$$

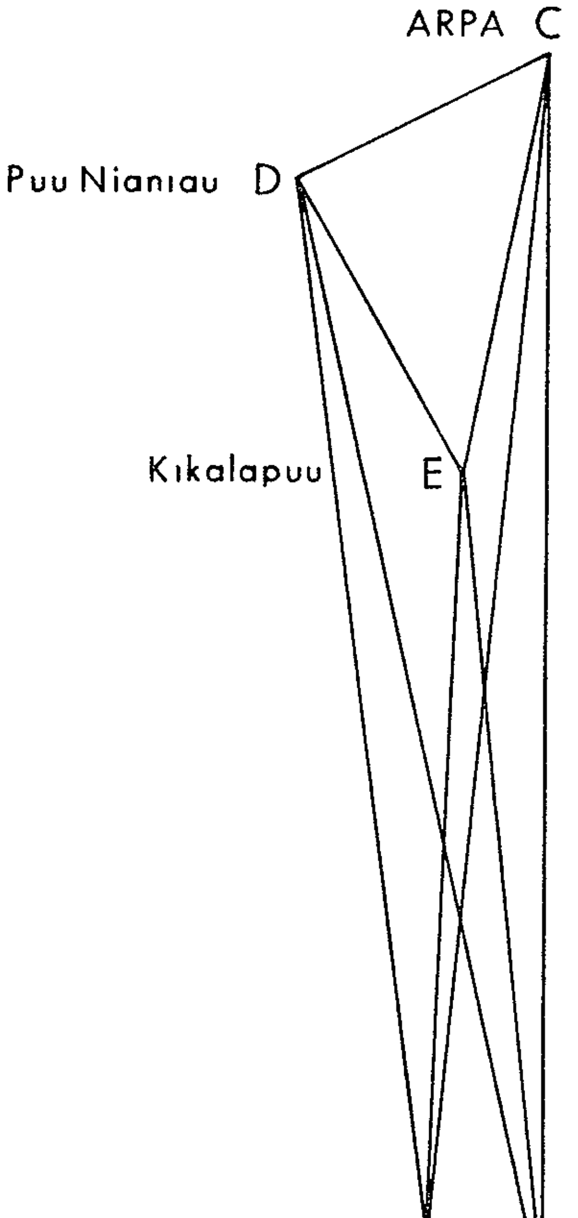

Fig VIII-1

The equations for the closure error now read similar to (VIII-2)

$$
\begin{aligned}
&F_1\ (AB, BC, CD, DA, AC, BD) = A + B + C + D - 360^\circ &&= \omega_1 \\
&F_2\ (CD, DA, AC, AE, CE, DE) = AEC + CED + DEA - 360^\circ &&= \omega_2 \qquad \text{(VIII-12)} \\
&F_3\ (BC, CD, BD, BE, CE, DE) = BED + BEC + CED - 360^\circ &&= \omega_3
\end{aligned}
$$

The closure errors ω_1, ω_2 and ω_3 are reduced to zero by the adjustments δ_{xy} to the individual 10 lines

$$
\begin{aligned}
&F_1\ (AB + \delta_{AB}, \quad , BD + \delta_{DB}) = 0 \\
&F_2\ (CD + \delta_{CD}, \quad , DE + \delta_{DE}) = 0 \qquad \text{(VIII-13)} \\
&F_3\ (BC + \delta_{BC}, \quad , DE + \delta_{DE}) = 0
\end{aligned}
$$

The Taylor series development of the three F_i's similar to (VIII-4) gives

$$
\text{(VIII-14)}
$$

$$
\begin{aligned}
&F_1 + \frac{\partial F_1}{\partial AB}\,\delta_{AB} + \frac{\partial F_1}{\partial BC}\,\delta_{BC} + \frac{\partial F_1}{\partial CD}\,\delta_{CD} + \frac{\partial F_1}{\partial DA}\,\delta_{DA} + \frac{\partial F_1}{\partial AC}\,\delta_{AC} + \frac{\partial F_1}{\partial BD}\,\delta_{BD} = 0 \\
&F_2 + \frac{\partial F_2}{\partial CD}\cdot\delta_{CD} + \frac{\partial F_2}{\partial DA}\cdot\delta_{DA} + \frac{\partial F_2}{\partial AC}\,\delta_{AC} + \frac{\partial F_2}{\partial AE}\cdot\delta_{AE} + \frac{\partial F_2}{\partial CE}\cdot\delta_{CE} + \frac{\partial F_2}{\partial DE}\cdot\delta_{DE} = 0 \\
&F_3 + \frac{\partial F_3}{\partial BC}\,\delta_{BC} + \frac{\partial F_3}{\partial CD}\,\delta_{CD} + \frac{\partial F_3}{\partial BD}\,\delta_{BD} + \frac{\partial F_3}{\partial BE}\,\delta_{BE} + \frac{\partial F_3}{\partial CE}\,\delta_{CE} + \frac{\partial F_3}{\partial DE}\cdot\delta_{DE} = 0
\end{aligned}
$$

For further equations we number the lines from 1 to 10 in the order AB, BC, CD, DA, AC, BD, AE, BE, CE, DE and call the partial derivatives in Eq (VIII-14) a_{1i}, a_{2i} and a_{3i} where $i = 1,2, \quad ,10$ Since not all of the a_{1i}, a_{2i} and a_{3i} appear in (VIII-14) we set the nonexisting ones = zero, that is

$$a_{1i} = 0 \text{ for } i = 7,8,9,10$$

$$a_{2i} = 0 \text{ for } i = 1,2,6,8$$

$$a_{3i} = 0 \text{ for } i = 1,4,5,7$$

The three condition equations for the 10 line adjustments δ_i corresponding to (VIII-14a) then read

$$F_\ell (AB + \delta_1, \quad , DE + \delta_{10}) = \omega_\ell + \Sigma\, a_{\ell i}\delta_i = 0 \qquad \text{(VIII-14a)}$$

$$\ell = 1,2,3$$

$$i = 1,2, \quad 10$$

The $\Sigma\, p_i \delta_i \delta_i$ is minimized for the same δ_i's as the three independent $F_\ell(AB + \delta_1, \ldots, DE + \delta_{10})$. Therefore similar to (VIII-5) we minimize

$$S = \tfrac{1}{2} \sum_i p_i \delta_i \delta_i + K_1 \left(\omega_1 + \sum_i a_{1i} \delta_i\right) + K_2 \left(\omega_2 + \Sigma\, a_{2i} \delta_i\right) + K_3 \left(\omega_3 + \Sigma\, a_{3i} \delta_i\right) \qquad \text{(VIII-15)}$$

by setting the partial derivatives of S with respect to δ_j equal to zero

$$\frac{\partial S}{\partial \delta_j} = p_j \delta_j + K_1\, a_{1j} + K_2\, a_{2j} + K_3\, a_{3j} = 0$$

or

$$-\delta_j = + K_1 \frac{a_{1j}}{p_j} + K_2 \frac{a_{2j}}{p_j} + K_3 \frac{a_{3j}}{p_j} \qquad \text{(VIII-16)}$$

Substituting for δ_j from the last equation back into the condition Eqs., (VIII-14a) results in three "normal" equations for the three unknown "condition correlates" K_1, K_2 and K_3

$$\begin{aligned}
K_1\, \Sigma \frac{a_{1i}^2}{p_i} + K_2\, \Sigma \frac{a_{1i} a_{2i}}{p_i} + K_3\, \Sigma \frac{a_{1i} a_{3i}}{p_i} - \omega_1 &= 0 \\
K_1\, \Sigma \frac{a_{2i} a_{1i}}{p_i} + K_2\, \Sigma \frac{a_{2i}^2}{p_i} + K_3\, \Sigma \frac{a_{2i} a_{3i}}{p_i} - \omega_2 &= 0 \qquad \text{(VIII-17)} \\
K_1\, \Sigma \frac{a_{3i} a_{1i}}{p_i} + K_2\, \Sigma \frac{a_{3i} a_{2i}}{p_i} + K_3\, \Sigma \frac{a_{3i}^2}{p_i} - \omega_3 &= 0
\end{aligned}$$

Substituting the three solutions of K_ℓ back into (VIII-16) then gives the line adjustment δ_i.

The "standard error of unit weight" is given by

$$\sigma = \frac{\sqrt{\Sigma\ p_i\ \delta_i \delta_i}}{\sqrt{r}} = \frac{\sqrt{+K_1\ \omega_1 + K_2\ \omega_2 + K_3\ \omega_3}}{\sqrt{3}} \qquad \text{(VIII-18)}$$

After considerable discussion on the use of the weights p_i, it was decided to set them equal to 1, because differences in the residuals δ_i obtained for the Luke-ARPA-Puu Nianiau Pier 2 quadrilateral with a centerpoint at Kilalapuu and the two diagonals by using either p = 1 or $p = 1/s^2$ all were less than 2 mm and the σ Eq. (VIII-18) was about 7 mm, after the elevation of the ARPA marker had been changed to minimize the adjustments (see Section XII).

A sample output is presented at the end of Appendix I.

IX SUMMARY OF THE LASER LINES MEASURED ON MAUI IN 1977

In the following Table IX-1, a summary is given of all lines measured on the Island of Maui during the summer, 1977. The information given includes the number of line, date when measured, marker-to-marker chord distance, standard deviation σ_o of one reduced range distance from the mean standard deviation of the mean, σ_M, and the final mean length of the line if several measurements were made The average number of laser range readings of all the lines was 47

TABLE IX-1

NO.	LINE	DATE 1977	LINE LENGTH m	σ_o mm	σ_M mm	Mean Line Length m
1	ARPA - LURE	6 - 21	227 301	±16 2	±3 4	
		7 - 28	227 297	9 5	1 3	227 299
2	Mees - LURE	6 - 21	119 481	2 4	0 4	
		7 - 28	119 501	3 8	0 5	119 491
3	ARPA - Mees	6 - 21	247 954	8 5	1 2	
		7 - 28	247 960	5 0	0 7	247 957
4	Luke - ARPA up	6 - 15	31,397 898	2 6	0 6	
	down	6 - 15	31,397 916	4 2	0 6	31,397 907
5	Pier 2 - ARPA up	6 - 21	30,291 514	4 4	1 0	
	down	6 - 21	30,291 514	3 7	0 7	30,291 514
6	Luke - Puu Nianiau up	6 - 21	28,842 961	3 4	0 5	
	down	6 - 21	28,842 962	5 4	1 3	28,842 962
7	Pier 2 - Puu Nianiau up	6 - 21	27,068 889	5 2	1 3	27,068 889
8	Luke - Kikalapuu up	6 - 17	20,699 236	6 5	1 2	
	down	6 - 17	20,699 242	4 9	0 8	20,699 239
9	Pier 2 - Kikalapuu up	6 - 20	19,349 018	8 2	1 0	
	down	6 - 20	19,349 024	6 7	1 6	19,349 021
10	Kikalapuu - ARPA up	7 - 26	11,111 220	2 5	0 4	
	down	7 - 26	11,111 227	3 3	0 6	11,111 224
11	Kikalapuu - Puu Nianiau up	7 - 26	8,745 329	2 8	0 4	
	down	7 - 26	8,745 336	1 9	0 4	8,745 333
12	ARPA - Puu Nianiau	7 - 28	7,278 940	9 4	1 4	7,278 940
13	LURE - Puu Nianiau	7 - 28	7,349 130	9 7	1 1	7,349 130
14	Luke - Pier 2	4 - 28	3,274 260	1 9	0 3	
		4 - 28	3,274 260	2 6	0 4	3,274 260
15	Luke - Wailuku North	4 - 28	2,469 156	1 6	0 2	
		5 - 1	2,469 157	1 6	0 6	
		5 - 1	2,469 155	1 6	0 3	2,469 156
16	Pier 2 - Wailuku North	5 - 4	3,482 199	4 4	0 4	3,482 199
17	Luke - Puu Olai	4 - 28	27,459 363	4 1	0 7	
		4 - 30	27,459 367	2 6	0 3	
		4 - 30	27,459 364	4 4	0 6	
		6 - 13	27,459 367	6 0	0 5	27,459 365

TABLE IX-1 (cont)

18	Puu Mahoe - Puu Olai up	6 - 17	5,883 510	1 2	0 3	
	down	6 - 17	5,883 510	1 2	0 3	5,883 510
19	Puu Olai - Lighthouse	4 - 30	6,900 462	3 8	0 4	
		4 - 30	6,900.465	2 6	0 4	6,900 464
20	Puu Mahoe - Lighthouse up	6 - 17	5,589 869	4 8	1 1	
	down	6 - 17	5,589 873	1 7	0 7	5,589 869
22	Puu Mahoe - La Perouse	4 - 29	4,512 956	1 5	0 2	
		4 - 29	4,512 956	1 6	0 2	4,512 956
23	Mees - Lighthouse up	7 - 26	21,407 534	4 9	0 9	
	down	7 - 26	21,407 534	5 8	0 8	21,407 534
29	Wolfe's Rock - Hana Airport	7 - 29	3,023 884	4 6	0 7	3,023 884
30	Waterpipe - Hana Airport	7 - 29	3,474 112	5 5	0 6	3,474.112
31	Wolfe's Rock - Carter's Cliff	7 - 29	1,989 646	5 6	0 6	1,989 646
32	Waterpipe --Carter's Cliff	7 - 29	1,986 969	3 8	0 5	1,986 969
33	Carter's Cliff - Hana Airport	7 - 30	2,353 456	2 1	0 3	2,353 456
34	Wolfe's Rock - Waterpipe	7 - 30	629 559	4 0	0 6	629 559
35	Hana Cross - Hana Prior	7 - 30	1,344 476	5 8	0 8	1,344 476
36	Hana Cross - North Hana Bay	7 - 30	1,567 160	4 0	0 5	1,567 160
37	Hana Pier - North Hana Bay	7 - 30	911 663	4 0	0 5	911 663

In Table IX- 2, all of those lines are given which are involved either in the comparison of the old Hawaiian geodetic and the new laser survey or in the computation of coordinates in the present trilateration network All lines are given as spatial chord distances, ellipsoidal arc distances, and HTM plane distances in meters

TABLE IX- 2

No	Line	Spatial Chord Distance	Ellipsoidal Arc Distance	Plane Distance
1	ARPA - LURE	227 299	226 668	226 666
2	Mees - LURE	119 491	119 113	119 112
3	ARPA - Mees	247 957	247 749	247 747
4	Luke - ARPA	31,397 907	31,252 266	31,251 588
5	Pier 2 - ARPA	30,291 514	30,132 223	30,131.599
6	Luke - Puu Nianiau	28,842 962	28,769 051	28,768 443
7	Pier 2 - Puu Nianiau	27,068 889	26,984 017	26,983 473
8	Luke - Kikalapuu	20,699 239	20,687 295	20,686 788
9	Pier 2 - Kikalapuu	19,349 021	19,333 215	19,332 759
10	Kikalapuu - ARPA	11,111 224	10,871 767	10,871 607
11	Kikalapuu - Puu Nianiau	8,745 333	8,641 298	8,641 175
12	ARPA - Puu Nianiau	7,278 940	7,214 236	7,214 161
13	LURE - Puu Nianiau	7,349 130	7,282 968	7,282 893
14	Luke - Pier 2	3,274 260	3,272 955	3,272 860
15	Luke - Wailuku North	2,469 156	2,469 110	2,469 037
16	Pier 2 - Wailuku North	3,482 199	3,480 808	3,480 707
17	Luke - Puu Olai	27,459 365	27,458 940	27,458 162

X COORDINATE COMPUTATIONS OF THE TERMINAL POINTS OF THE LASER LINES

To make it possible to monitor the actual annual movements (direction and distance) of the LURE Observatory with respect to the various laser line terminals on the west slope of Mt Haleakala, we have computed the coordinates of the laser terminals together with the coordinates of the LURE observatory The computation is based on the adjusted laser line lengths on the Hawaiian Zone 2 Transverse Mercator Plane (HTM) The HTM plane coordinates X and Y are computed on that plane, the geographic coordinates ϕ and λ are computed on the Clarke 1866 reference ellipsoid, and the earth centered Cartesian ("Space Rectangular") coordinates X, Y, Z are computed in space with reference to the Clarke 1866 ellipsoid

The computations on the plane are carried out in the following way The HTS triangulation marker Luke (L) was selected as the reference center of the coordinate-system with the HGS marker at Puu Nianiau (PN) serving as the azimuth reference The plane coordinates of the two markers were obtained from the USCGS Form 609 The azimuth A_{L-PN} from Luke to Puu Nianiau thus will be given by

$$\sin A_{L-PN} = \frac{\Delta X}{(\Delta X^2 + \Delta Y^2)^{\frac{1}{2}}} \qquad \cos A_{L-PN} = \frac{\Delta Y}{(\Delta X^2 + \Delta Y^2)^{\frac{1}{2}}} \qquad \text{(X-1)}$$

where $\Delta X = X_{PN} - X_L$ and $\Delta Y = Y_{PN} - Y_L$

The plane coordinates of the Puu Nianiau marker in the laser-determined system are then obtained as follows.

$$\begin{aligned} X_{PN} &= X_L + d_{L-PN} \sin A_{L-PN} \\ Y_{PN} &= Y_L + d_{L-PN} \cos A_{L-PN} \end{aligned} \qquad \text{(X-2)}$$

where d_{L-PN} is the adjusted and properly centered laser line length L - PN on the plane The coordinates of any other point with known distances from L and PN can then be determined in the same coordinate system by the following way (see Laurila, 1976, pp 210, 211) With reference to Kikalapuu, for example, we have

$$\begin{aligned} X_K &= X_L + X'_K \cdot \frac{\Delta X}{d_{L-PN}} - Y'_K \frac{\Delta Y}{d_{L-PN}} \\ Y_K &= Y_L + X'_K \cdot \frac{\Delta Y}{d_{L-PN}} + Y'_K \cdot \frac{\Delta X}{d_{L-PN}} \end{aligned} \qquad \text{(X-3)}$$

In Eq 3, X'_K and Y'_K are plane coordinates of Kikalapuu given in the rectangular coordinate system Luke as the origin and the positive x-axis coinciding with the line Luke-Puu Nianiau Before application to Eq 3, X'_K and Y'_K are obtained from the following formulas

$$\begin{aligned} X'_K &= \frac{d_{L-K}^{\ 2} - d_{PN-K}^{\ 2} + d_{L-PN}^{\ 2}}{2\, d_{L-PN}} \\ Y'_K &= \pm(d_{L-K}^{\ 2} - X'^{\,2}_K)^{\frac{1}{2}} \end{aligned} \qquad \text{(X-4)}$$

where the sign of Y'_K depends on which side of the auxiliary X' axis the new point is located. If any point cannot be seen simultaneously from Luke and Puu Nianiau, another "baseline" can be found from already determined new coordinates and Eqs. 3 and 4 can be applied as before.

On the island of Maui the local Transverse Mercator map plane is utilized by the USCGS in such a way that the origin of the Y-coordinate is located at latitude ϕ = 20°20' and the central meridian is assigned the scale factor value of 0.999966667. The Universal Transverse Mercator formulas to compute geographic coordinates ϕ and λ from the plane coordinates X and Y (see Laurila <u>et al.</u>, 1969) are therefore modified as follows.

The so-called "foot-point latitude" of a parallel which crosses the central meridian at the distance Y from the equator is first found by iterative process from the equation

$$\frac{Y/0.999966667 + 2,249,134.918}{a} = (1 - \frac{1}{4} e^2 - \frac{3}{64} e^4 - \frac{5}{256} e^6) \phi_1$$

$$- (\frac{3}{8} e^2 + \frac{3}{32} e^4 + \frac{45}{1024} e^6) \sin 2\phi_1$$

$$+ (\frac{15}{256} e^4 + \frac{45}{1024} e^6) \sin 4\phi_1$$

$$- \frac{35}{3072} e^6 \sin 6\phi_1 \qquad \text{(X-5)}$$

where a is the semimajor axis of the Clarke 1866 ellipsoid and e^2 is the eccentricity square. The final coordinates ϕ and λ will then be

$$\phi = \phi_1 - \frac{\tan \phi_1 (\Delta X/0.999966667)^2}{2 M_1 N_1} + \frac{\tan \phi_1 (5 + 3 \tan^2 \phi_1) (\Delta X/0.999966667)^4}{24 N_1^3 M_1}$$

$$\Delta\lambda = \frac{(\Delta X/0.999966667)}{N_1 \cos \phi_1} - \frac{(1 + 2 \tan^2 \phi_1) (\Delta X/0.999966667)^3}{6 N_1^3 \cos \phi_1} \qquad \text{(X-6)}$$

where $\Delta X = X - 152,400.3$ and $\lambda = 156°40'00."0000 - \Delta\lambda$

The formulas to compute the earth-centered Cartesian coordinates can be found from any standard textbook in mathematics.

$$X = (N + H) \cos \phi \cos \lambda$$

$$Y = (N + H) \cos \phi \sin \lambda \qquad \text{(X-7)}$$

$$Z = (N (1 - e^2) + H) \sin \phi$$

where X is in the equatorial plane towards the Greenwich meridian (λ = 0), Y is toward λ = 90°E, and Z toward the north pole and λ positive to the east.

Coordinates were computed for all laser terminals which formed closed triangles or more complex figures to be tied to one common trilateration network. Those terminals were: Wailuku North, Luke, Pier 2, Kikalapuu, Puu Nianiau, ARPA, Mees, and LURE Of the 8 terminals, Luke, ARPA, Puu Nianiau, Pier 2, and Kikalapuu formed a quadrilateral with Kikalapuu as the center point All lines in this figure were adjusted by the combined least squares conditional adjustment of a quadrilateral with diagonals and a center point (see VIII) All lines terminating to Luke were given eccentricity corrections to correct the line lengths from the UH marker to the HTS marker at Luke

Table X-1 tabulates The reduced laser line lengths on the Hawaiian Transverse Mercator (HTM) plane, adjustment correction, d_A, eccentricity correction, d_E, and the final plane distances to be used as input in the coordinate computations, Eqs 1 - 7 All distances and corrections are given in meters

TABLE X-1

No	Line	Reduced Line Length	d_A	d_E	Final Line Length
4	Luke - ARPA	31,251 588	-0 006	+0 020	31,251 602
8	Luke - Kikalapuu	20,686 788	+0 008	+0 072	20,686 868
6	Luke - Puu Nianiau	28,768 443	-0 002	+0 135	28,768 576
14	Luke - Pier 2	3,272 860	-0-	+0 480	3,273 340
15	Luke - Wailuku North	2,469 037	-0-	+0 312	2,469 349
12	ARPA - Puu Nianiau	7,214 161	-0 001	-0-	7,214 160
5	ARPA - Pier 2	30,131 599	+0 004	-0-	30,131 603
10	ARPA - Kikalapuu	10,871 607	+0 002	-0-	10,871 609
3	ARPA - Mees	247.747	-0-	-0-	247 747
1	ARPA - LURE	226 666	-0-	-0-	226 666
2	LURE - Mees	119.112	-0-	-0-	119 112
7	Puu Nianiau - Pier 2	26,983 473	-0 001	-0-	26,983 472
11	Puu Nianiau - Kikalapuu	8,641 175	+0 003	-0-	8,641 178
13	Puu Nianiau - LURE	7,282 893	-0-	-0-	7,282 893
9	Pier 2 - Kikalapuu	19,332 759	-0 004	-0-	19,332 755
16	Pier 2 - Wailuku North	3,480 707	-0-	-0-	3,480 707

In Table X- 2 the computed plane coordinates X and Y, the geographic coordinates ϕ and λ, and the earth-centered Cartesian coordinates X, Y, and Z are given, together with the elevations, H, of the laser line terminals From the Cartesian coordinates the marker-to-marker spatial chord distances were computed for the lines in Table X-2 to detect any computational or procedural errors made during the long process

TABLE X- 2

		HTM Plane Coordinates		Geographic Coordinates	
		X	Y	φ	λ
Wailuku North	99 70	169,287 755	63,323 975	20°54'18 "98465	156°30'15 "62664
Luke	93 84	169,836 967	60,916 476	20°53'00 "67856	156°29'56 "70865
Pier 2	2 28	172.679 107	62,540 359	20°53'53 "38016	156°28'18 "30556
Kikalapuu	755 40	187,452 500	50,070 302	20°47'07 "08278	156°19'48 "01819
Puu Nianiau	2087 90	196,029 256	49,017 108	20°46'32 "18231	156°14'51 "56382
ARPA	3034 34	194,662 605	41,933 580	20°42'41 "95232	156°15'39 "42804
Mees	3040 99	194,799 857	41,727 326	20°42'35 "23409	156°15'34 "70265
LURE	3049 74	194,863 264	41,828 159	20°42'38 "50781	156°15'32 "50264

TABLE X-II (Cont)

	Cartesian Coordinates		
	X	Y	Z
Wailuku North	-5,466,776 796	-2,376,529 752	2,261,502 499
Luke	-5,467,340 605	-2,377,371 090	2,259,250 267
Pier 2	-5,465,598 295	-2,379,714 623	2,260,732 143
Kikalapuu	-5,464,410 649	-2,395,296 294	2,249,322 254
Puu Nianiau	-5,462,451 262	-2,403,802 752	2,248,791 331
ARPA	-5,466,115 547	-2,403,901 352	2,242,502 749
Mees	-5,466,133 081	-2,404,058 510	2,242,311 759
LURE	-5,466,082 326	-2,404,105 766	2,242,409 067

of reductions from the original spatial chord distances back to the same distances via the Cartesian coordinates The equivalent distances were compared after the original chord distances were compensated with the adjustment corrections and the following spatial eccentricity corrections

Line	Correction
Luke - ARPA	+0 108 m
Luke - Kikalapuu	+0 102 m
Luke - Puu Nianiau	+0 200 m
Luke - Pier 2	-0 454 m
Luke - Wailuku North	+0 312 m

The analysis revealed that after the reduction process spatial chord distances-ellipsoidal arc distances-plane distances-plane coordinates-ellipsoidal coordinates-Cartesian space coordinates-spatial chord distances, the average difference between the computed and the original distance was 0 9 mm and the maximum difference was 2 0 mm.

The conditional least squares adjustment, a basis for the line lengths used in the coordinate computations has been performed in three different combinations adjustment of Luke-ARPA-Puu Nianiau-Pier 2 quadrilateral with diagonals only (1 condition) with the standard deviation of one line measurement, $\sigma = \pm 4$ mm, adjustment of the above quadrilateral with center point only, Kikalapuu as the center (1 condition) with the standard deviation of one line measurement, $\sigma = \pm 7$ mm, adjustment of the above quadrilateral with combined diagonals and center point (3 conditions) with the standard deviation of one line measurement, $\sigma = \pm 7$ mm In the coordinate computations, the corrections to the lines were those taken from the last combination of adjustments

At this stage it is to be emphasized that the standard deviations stated above merely indicate the uncertainties in the line lengths composed of the combined effects of errors in line measurements and errors in the station elevations This part is intended to serve primarily as a guideline for the procedure to be followed After the National Geodetic Survey has completed the first order levelling on Maui all line lengths and coordinates will be recomputed

XI COMPARISON BETWEEN OLD HAWAIIAN TRIANGULATION DISTANCES AND PRESENT LASER DISTANCES

During the process of the 1977 laser survey on the island of Maui, four old Hawaiian geodetic triangulation points have been occupied and data obtained for comparison The triangulation stations are Luke, established in 1912 by the Hawaiian Territorial Survey (HTS), Puu Olai, established by the Hawaiian Government Survey (HGS) in 1879 and resurveyed by HTS in 1929, Kikalapuu, established in 1950 by HTS, Puu Nianiau, established by HGS in 1877 Also, a permanent retroreflective prism was set at the triangulation station Hanakauhi, established by HTS in 1950 Laser survey to this point has not yet been made These five stations provide five lines for comparison,(see Fig II-1) namely

No	Line
6	Luke - Puu Nianiau
8	Luke - Kikalapuu
11	Kikalapuu - Puu Nianiau
17	Luke - Puu Olai
27	Puu Nianiau - Hanakauhi

In Table XI-1a the plane coordinates X and Y of the triangulation stations in the Transverse Mercator, Hawaiian Zone 2 are obtained from the U S Coast and Geodetic Survey Form 709 Coordinates are converted from the original units of feet to meters directly without assigning the central meridian a new reference value The geographic coordinates ϕ and λ and the elevations are obtained from USCGS Form 28 BT and have been recomputed to add the fourth and fifth decimal in seconds of arc in ϕ and λ

TABLE XI-1a

Station	Elevation H_m	X_m	Y_m	ϕ	λ
Luke	92 90	169,836 967	60,916 476	20°53'00 "67856	156°29'56 "70865
Puu Olai	109 60	174,822 112	33,915 163	20°38'22 "43766	156°27'05 "47173
Kikalapuu	755 40	187,452,832	50,070 238	20°47'07 "08065	156°19'48 "00673
Puu Nianiau	2087 90	196,029 638	49,016 935	20°46'32 "17664	156°14'51 "55064
Hanakauhi	2715 00	202,855 513	44,891.956	20°44'17 "42063	156°10'55 "98465

In Table XI-1b the earth-centered Cartesian coordinates X, Y, and Z are computed, together with the curvature radii N of the prime vertical for each triangulation point The reference ellipsoid used to compute X, Y, and Z as a function of ϕ, λ and the elevation H is that of Clarke 1866 with the semi-major axis, a = 6378,206 4 m and the eccentricity square, e^2 = 0 006768658 (Chapter VII)

TABLE XI-1b

Station	N_m	X_m	Y_m	Z_m
Luke	6,380,951 105	-5,467,340 605	-2,377,371 090	2,259,250 267
Puu Olai	6,380,890 099	-5,474,156 011	-2,385,740 403	2,234,001 635
Kikalapuu	6,380,926 472	-5,464,410 538	-2,395,296 607	2,249,322 193
Puu Nianiau	6,380,924 045	-5,462,451 165	-2,403,803 126	2,248,791 168
Hanakauhi	6,380,914 686	-5,461,582 868	-2,410,870 104	2,245,136 867

In Table XI-2 distances between the HGS and HTS markers are given for checking purpose and for further use in three systems, namely

(a) marker-to-marker chord distance (reduced laser line)

(b) distance along ellipsoidal surface (geodetic distance)

(c) distance on the TM plane (map distance)

The marker-to-marker distance is obtained directly from the Cartesian coordinates, X, Y, and Z Similarly, the map distance is obtained directly from the plane coordinates X, and Y To determine the geodetic distance along the ellipsoidal surface, the following formula was adapted (Laurila, 1976, pp 117 and 215)

$$d_A = \left[4N_1N_2 \cos\phi_1 \cos\phi_2 \sin^2\frac{\Delta\lambda}{2} + (N_1 \cos\phi_1 - N_2 \cos\phi_2)^2 + (1 - e^2)^2 (N_1 \sin\phi_1 - N_2 \sin\phi_2)^2\right]^{\frac{1}{2}} + \frac{d_C^{\,3}}{24\, R_m^{\,2}} \qquad \text{(IX-1)}$$

where the subscripts refer to the terminals of the line, $\Delta\lambda$ is the longitude difference between the terminal points and R_m is the mean curvature radius In Eq (XI-1) the bracket term represents the ellipsoidal chord distance and equals d_C The derivation of d_C is rigorous and exact The second term represents the ellipsoidal chord-to-arc reduction and is correct within one-half millimeter at any laser line on Maui

The mean curvature radius R_m is obtained from the following formula

$$R_m = (M \cdot N)^{\frac{1}{2}} \qquad \text{(IX-2)}$$

where M is the meridian curvature radius Since R_m is not sensitive in the small correction term, Eq IX-1, the following values of M and N at Puu Nianiau were adapted

$M = 6343\ 1$ km
$N = 6380\ 9$ km

for the island of Maui, yielding the mean curvature radius

$R_m = 6362\ 0$ km

TABLE XI-2

Line No	Line Location	Plane Distance m	Ellipsoidal Distance m	Chord Distance m
6	Luke - Puu Nianiau	28,768 995	28,769 604	28,843 577
8	Luke - Kikalapuu	20,687 184	20,687 692	20,699 664
11	Kikalapuu - Puu Nianiau	8,641 241	8,641 364	8,745 399
17	Luke - Puu Olai	24,457 650	27,458 430	27,458 852
27	Puu Nianiau - Hanakauhi	7,975 464	7,975 512	8,003 127

At stations Kikalapuu and Puu Nianiau, laser and the reflector were set exactly on the HTS and HGS markers At stations Luke, Puu Olai, and Kanakauhi University of Hawaii brass markers were offset from the HTS and HGS markers as follows

> At Luke, the UH marker is 0 94 m above the HTS marker The bearing from Puu Nianiau to UH marker observed clockwise at the HTS marker is A_1 = 285°14'46" and from Puu Olai similarly A_2 = 230°26'50" The distance from the HTS marker to UH marker is s = 0 513 m
>
> At Puu Olai, the UH marker is 0 50 m above the HGS marker The bearing from Luke to UH marker observed clockwise at the HGS marker is A = 148°28' The distance from the HGS marker to the UH marker is s = 0 659 m
>
> At Hanakauhi, the UH marker is 0 39 m above the HTS marker The bearing from Puu Nianiau to UH marker observed at the HTS marker is A = 0°00' The distance from the HTS marker to the UH marker is s = 3 785 m

Prior to the comparison between the old Hawaiian geodetic surveying and the present laser surveying, all laser line lengths were reduced to HGS and HTS new marker-to-marker distances This was achieved by utilizing the above offset constants to give dX and dY corrections to the laser determined plane coordinates X and Y, to give $d\phi$ and $d\lambda$ corrections to the laser determined geographic coordinates ϕ and λ, to give $d\phi$, $d\lambda$, and dH corrections and consequently dX, dY, and dZ corrections to the laser determined Cartesian X, Y, and Z coordinates

In Table XI-3, final line lengths and their differences are given, for checking purpose, in the above three systems

TABLE XI-3

Line	Old Geodetic Survey	Laser Survey	Laser-Old Survey
	IN CARTESIAN SYSTEM		
Luke - Puu Nianiau	28,843 577	28,843 158	-0 419
Luke - Kikalapuu	20,699 664	20,699 348	-0 316
Kikalapuu - Puu Nianiau	8,745 399	8,745 336	-0 063
Luke - Puu Olai	27,458 852	27,458 476	-0 376
	IN GEOGRAPHIC SYSTEM		
Luke - Puu Nianiau	28,769 604	28,769 184	-0 420
Luke - Kikalapuu	20,687 692	20,687 375	-0 317
Kikalapuu - Puu Nianiau	8,641 364	8,641 301	-0 063
Luke - Puu Olai	27,458 430	27,458 051	-0 379
	IN PLANE SYSTEM		
Luke - Puu Nianiau	28,768 995	28,768 576	-0 419
Luke - Kikalapuu	20,687 184	20,686 868	-0 316
Kikalapuu - Puu Nianiau	8,641 241	8,641 178	-0 063
Luke - Puu Olai	27,457 650	27,457 273	-0 377

The obvious correlation between the residuals and the line length suggests that there is significant scale error present in the old Hawaiian triangulation network From each of the four lines the scale correction factor was computed yielding the following values

Luke - Puu Nianiau	K = 0 99998544
Luke - Kikalapuu	K = 0 99998472
Kikalapuu - Puu Nianiau	K = 0 99999273
Luke - Puu Olai	K = 0 99998626

Since the scale correction factor from the line Kikalapuu - Puu Nianiau differed essentially from the rest, a weighted mean was computed with the squares of distances as weights This produced a common scale correction factor, K = 0 99998585 This factor was applied to the marker-to-marker distances (in the Cartesian system) yielding the following results

Line	Old Geodetic Survey	Laser Survey	Laser-Old Survey
Luke - Puu Nianiau	28,843 169	28,843 158	-0 011
Luke - Kikalapuu	20,699 371	20,699 348	-0 023
Kikalapuu - Puu Nianiau	8,745 275	8,745 336	+0 061
Luke - Puu Olai	27,458 463	27,458 476	+0 013

Figure XI-1 shows the differences between the old line lengths and the one measured by the present laser survey as given in Table XI-3 The straight line drawn in this figure fits the 3 longest lines within plus or minus 2 3 cm The older line measurements are about 1 4 cm/km longer than the new ones The 6-cm deviation from (the scale factor) line for the distance Kikalapuu-Puu Nianiau, however, is not explained and may be due to some motion of the Kikalapuu bench mark

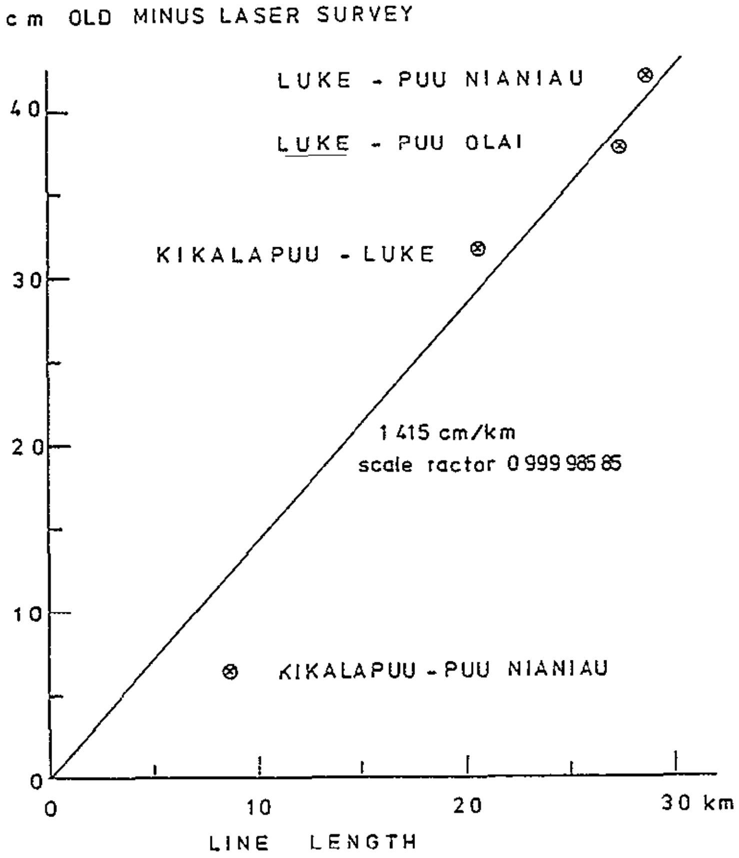

Fig XI-1

XII. DETERMINATION OF STATION ELEVATION BY LASER

Spacial Intersection

The elevation of ARPA in the Luke quadrilateral, H = 3033 51 m, was initially obtained by a local differential levelling from the nearby HGS triangulation point Kolekole The elevation of Kolekole, H = 3051 60, is based on vertical angle trigonometric measurements made in 1876 While executing a conditional adjustment of the quadrilateral Luke, Kikalapuu, Puu Nianiau, and Pier 2, the standard deviation of one line measurement after adjustment proved to be ± 4 mm When ARPA was added into the adjustment as a new corner point in the quadrilateral with Kikalapuu as the center point, the standard deviation after the adjustment became ± 38 mm

This phenomenom clearly indicated that the elevation of Kolekole and consequently that of ARPA was significantly in error To find a better value for ARPA elevation, among other alternatives, the following spatial intersection procedure was adapted According to Chapter X, the Hawaiian Transverse Mercator plane coordinates X and Y were first computed for Luke, Kikalapuu, Puu Nianiau, and Pier 2 based on the adjusted line lengths in this quadrilateral (ARPA excluded) From the plane coordinates, the geographic coordinates ϕ and λ were computed and finally, the earth centered Cartesian coordinates determined by the geographic coordinates and elevations were used to intercept ARPA from Luke, Kikalapuu, and Puu Nianiau (for checking purpose also from Pier 2, Kikalapuu, and Puu Nianiau)

The spatial, marker-to-marker chord distances from Luke, Kikalapuu, and Puu Nianiau were used to determine the Cartesian coordinates X_A, Y_A, and Z_A of ARPA by simple simultaneous solution of three unknowns and three equations The line Luke- ARPA, for example, yields the following equation

$$D^2_{L-A} = (X_A - X_L)^2 + (Y_A - Y_L)^2 + (Z_A - Z_L)^2 \qquad \text{(XII-1)}$$

This equation was linearized by writing the square terms in the unknown X_A, Y_A, and Z_A as

$$(X_A - X_L)^2 = (X_A - X_L)\ (X_A - X_L)$$

and replacing one of the X_A's on the right hand side by an approximate value $\bar{X}_A$, so that

$$(X_A - X_L)^2 = X_A(\bar{X}_A - X_L) - X_L(\bar{X}_A - X_L) \qquad \text{(XII-2)}$$

and similarly for the Y and Z terms so that finally

$$D^2_{L-A} + X_L(\bar{X}_A - X_L) + Y_L(\bar{Y}_A - Y_L) + Z_L(\bar{Z}_A - Z_L)$$

$$= X_A\ (\bar{X}_A - X_L) + Y_A(\bar{Y}_A - Y_L) + Z_A(\bar{Z}_A - Z_L) \qquad \text{(XII-3)}$$

is linear in X_A, Y_A, Z_A and the left hand side is constant From the three Eqs of the form (XII-3), X_A, Y_A and Z_A were obtained by iteration The final longitude of ARPA is obtained directly from the Cartesian coordinates as follows

$$\lambda_R = -\tan^{-1}\left(\frac{Y_A}{X_A}\right) \qquad \text{(XII-4)}$$

The final latitude, ϕ_A, can be obtained from the following formula (see Laurila, 1976, p. 197).

$$\phi_A = \tan^{-1}\left(\frac{a+\overline{H}}{b+\overline{H}}\right)^2 \frac{Z_A \sin\lambda_A}{X_A} \qquad \text{(XII-5)}$$

where $\overline{H}$ is the approximate (original) value for H, a and b are semimajor and semiminor axes of the Clarke 1866 ellipsoid.

The new elevation of ARPA is the H obtained from X_A (Y_A and Z_A for checking purpose).

$$H_A = \frac{X_A}{\cos\phi_A \cos\lambda_A} - N_A \qquad \text{(XII-6)}$$

$$H_A = -\frac{Y_A}{\cos\phi_A \sin\lambda_A} - N_A$$

$$H_A = \frac{Z_A}{\sin\phi_A} - N_A(1 - e^2)$$

where N_A is a function of ϕ_A (Eq. 5).

After the execution of this spatial intersection process, a new value for the elevation of ARPA was found, H_A = 3034.34 m. When this value, in turn, was applied to the conditional adjustment of the quadrilateral with the center point, the standard deviation of one line measurement after adjustment was reduced from ± 38 mm to ± 7 mm. Four iterations were needed to reach an agreement in X_A, Y_A, and Z_A within 0.1 mm.

Minimization of Quadrilateral Adjustment

An alternative to the spacial intersection method to obtain the ARPA station elevation consists of minimizing the standard error σ in the adjustment of the quadrilateral with diagonals and center point by the variation of the ARPA elevation, holding all other elevations fixed. For a given ARPA elevation, the measured laser line lengths are first projected on to the Hawaiian Transverse Mercator plane. The projected line lengths are then adjusted (Chapter VIII) resulting in a standard deviation that depends on the chosen height for ARPA. Figure XII-1 shows the standard deviation as a function of ARPA elevation. The indicated minimum of σ is near the elevation of 3034.30 meters, a few centimeters lower than the value of 3034.34 adopted to compute the final 1977 ARPA position from the intersection method.

The results indicate that, given the topography of the quadrilateral Luke, ARPA, Puu Nianiau and Pier 2 with the center point at Kikalapuu, elevations of other points could be obtained within a few centimeters by the use of laser line length measurements. In the case of the ARPA height determination the geometrical figure of the quadrilateral is rather ill-shaped as can be seen in Figure VIII-1 that is drawn to scale. The angle ECB at ARPA (C) is very small and small changes for example in the height of Luke (B) and especially Kikalapuu (E) would rotate the figure along AD and result in nearly twice that change for ARPA

Given that the adjustment of the quadrilateral with diagonals and center point in the Mercator plane has three conditions (see Chapter VIII), minimizing this adjustment by variation of the elevation of two of the five points is possible However, at this point we prefer to await the results of the first order leveling, to be carried out by the National Geodetic Survey We also plan to expand the figure by adding a few extra points (to the left and right in Figure VIII-1)

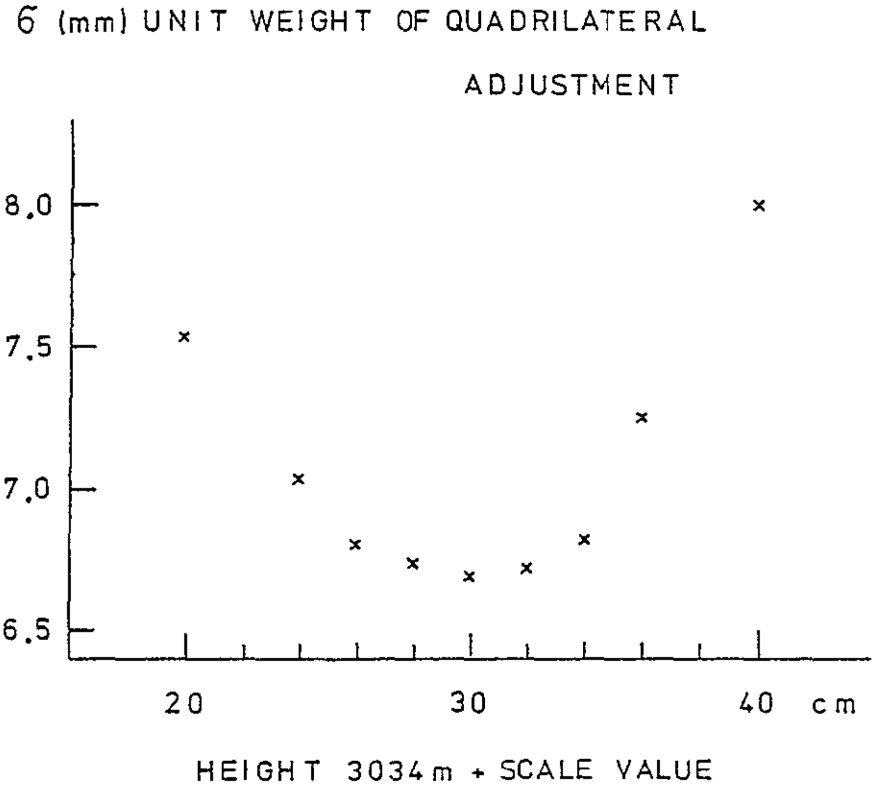

Fig XII-1

XIII ALTERNATIVE METHODS IN DETERMINING THE MEAN REFRACTIVE INDEX AND THE FINAL MARKER-TO-MARKER DISTANCE

To be used as backup methods in troubleshooting or just for the sake of general interest, the following alternatives are presented

The reduction of the individual length Ranges D between the laser and the reflector to the corresponding length Ranges D between the benchmarks is presented in Eq V-3 The reduction can also be made by utilizing the following formula

$$D_B = D + \Delta D \quad (XIII-1)$$

The correction term ΔD is determined as follows

$$\Delta D = - [D(1 - \frac{R}{R + (h_R + h_L)/2}) + \frac{H_L - H_R}{D} (h_L - h_R)] \quad (XIII-2)$$

where

R = earth radius (6371 km)

H_L = benchmark height of the laser station

H_R = benchmark height of the reflector station

h_L = height of the laser optical center from the benchmark

h_R = height of the reflector center from the benchmark

Derivation of Eq XIII-2 is based on simple, closed formulas The ultimate sign of the correction is obtained directly, as is the case also by utilizing Eq V-3

To compare the mutual agreement of these two approaches, the line Pier 2 - ARPA was selected as the basis for comparison with the following data

D = 30 291 km

H_L = 0 0023 km

H_R = 3 0335 km

h_L = 0 001365 km

h_R = 0 000807 km

The results by using Eqs V-3 and 4 and XIII-2 in the computation of ΔD yielded ΔD_1 = 50 68 mm and ΔD_2 = 50 67 mm, respectively This comparison indicates that the two approaches, in effect, produce identical results

To find out the validity of a polynomial approach in determining the mean refractive number $\bar{N}$ under various atmospheric (inversion) conditions, all long lines were computed by utilizing this approach also, in addition to numerical integration

The basic concept is to determine the refractive number N at various altitudes h by using Eq IV-2 and ground/helicopter-based observations of temperature, pressure, and humidity By placing the computed N-values, together with the given altitudes into the following formula,

$$N = A + Bh + Ch^2 + \tag{XIII-3}$$

the unknown coefficient A, B, C   can be solved by a least squares curve fit to the desired degree The mean refractive number between the terminal altitudes h_2 and h_1 is obtained by the expression,

$$\bar{N} = \frac{1}{h_2 - h_1} \int_{h_1}^{h_2} N \, dh \tag{XIII-4}$$

and thus, its value in terms of an instantaneous model atmosphere may be written as follows

$$\bar{N} = A \frac{(h^2_2 - h^2_1)}{2(h_2 - h_1)} B + \frac{(h_2^3 - h_1^3)}{3(h_2 - h_1)} C + \tag{XIII-5}$$

One advantage of this approach lies in the fact that in absence of a closure checkup achieved by flying the line at least twice, the strength of the model (standard error of $\bar{N}$) is directly obtainable from the least squares solution The summary of this procedure is as follows The standard deviation of one point-to-point N-measurement (standard deviation of unit weight) is

$$\sigma_{N_o} = \left(\frac{\sum_{i=1}^{n} v_i^2}{n - u} \right)^{\frac{1}{2}} \tag{XIII-6}$$

where v_i is the residual obtained as the difference between the observed N_o values, determined as a function of T, P, and e (Eq IV-2), and the N_c-values, computed by utilizing the polynom (XIII-3) and the solved coefficients A, B, C,   , n is the number of observations, and u is the number of unknown coefficients

The standard error of the mean refractive number, $\sigma_{\bar{N}}$, is then obtained as follows

$$\sigma_{\bar{N}} = \sigma_{N_o} (Q_{\bar{N}\,\bar{N}})^{\frac{1}{2}} \tag{XIII-7}$$

where $Q_{\bar{N}\,\bar{N}}$ is the weight number of the function $\bar{N}$ Its value, according to the standard error propagation, is

$$Q_{\bar{N}\,\bar{N}} = f'^2_A \cdot Q_{AA} + f'^2_B \cdot Q_{BB} + f'^2_C \cdot Q_{CC} ++ \; 2f'_A f'_B \cdot Q_{AB} + 2f'_A f'_C \cdot Q_{AC} + 2f'_B f'_C \cdot Q_{BC} +++ \tag{XIII-8}$$

where Q_{AA}, Q_{BB} Q_{AB} are the weight and correlation numbers of the coefficients A, B, C . , and f', f', f' are their partial derivatives

Applied in the type of polynomial we are using in this comparison study, Eq XIII-8 yields the following form

$$Q_{\overline{N}\overline{N}} = Q_{AA} + \frac{1}{4}\left[\frac{h^2_2 - h^2_1}{h_2 - h_1}\right]^2 Q_{BB} + \frac{1}{9}\left[\frac{h^3_2 - h^3_1}{h_2 - h_1}\right]^2 Q_{CC} ++ \left[\frac{h^2_2 - h^2_1}{h_2 - h_1}\right] Q_{AB} + \frac{2}{3}\left[\frac{h^3_2 - h^3_1}{h_2 - h_1}\right] Q_{AC} + \frac{1}{3}\left[\frac{(h^2_2 - h^2_1)(h^3_2 - h^3_1)}{(h_2 - h_1)^2}\right] Q_{BC} ++ \qquad \text{(XIII-9)}$$

A total of 11 lines were measured with the aid of a helicopter flying along the lines observing the T, P, and e data Ten lines were flown in both directions In Table 1 the mean refractive number $\overline{N}_N$ from numerical integration and $\overline{N}_M$ from atmospheric modelling, together with their differences $\Delta\overline{N}$ are presented Also, the standard error $\sigma_{\overline{N}_M}$ of the mean refractive number $\overline{N}_M$ is included In the case of the atmospheric modelling sixth order polynom was used in every line measurement

TABLE XIII-1

NO	Line	$\overline{N}_N$	$\overline{N}_M$	$\Delta\overline{N}$	$\sigma_{\overline{N}_M}$
4	Luke - ARPA up	238 8	238 7	-0 1	±0 1
4	Luke - ARPA down	238 3	238 2	-0 1	0 1
8	Luke - Kikalapuu up	266 3	266 3	0 0	(0 03)
8	Luke - Kikalapuu down	266 1	266 1	0 0	(0 03)
6	Luke - Puu Nianiau up	249 1	249 1	0 0	0 1
6	Luke - Puu Nianiau down	249 1	249 2	+0 1	0 1
5	Pier 2 - ARPA up	239 5	239 0	-0 5	0 2
5	Pier 2 - ARPA down	239 2	239 1	-0 1	0 1
7	Pier 2 - Puu Nianiau up	250 5	250 7	+0 2	0 1
9	Pier 2 - Kikalapuu up	267 0	266 8	-0 2	0 1
9	Pier 2 - Kikalapuu down	266 8	266 8	0 0	0 1
10	Kikalapuu - ARPA up	230 3	230 1	-0 2	0 2
10	Kikalapuu - ARPA down	229 6	229 8	+0 2	0 2
11	Kikalapuu - Puu Nianiau up	242 1	242 1	0 0	0 1
11	Kikalapuu - Puu Nianiau down	241 5	241 5	0 0	0 1
18	Puu Mahoe - Puu Olai up	267 4	267 3	-0 1	(0 04)
18	Puu Mahoe - Puu Olai down	267 4	267 3	-0 1	0 1
20	Puu Mahoe - Lighthouse up	268 6	268 6	0 0	(0 03)
20	Puu Mahoe - Lighthouse down	267 9	267 9	0 0	0 2
23	Mees - Lighthouse up	239 8	239 7	-0 1	0 1
23	Mees - Lighthouse down	239 1	239 1	0 0	(0 04)

From the 11 lines, 'Pier 2 - ARPA up' was the most unsuitable for atmospheric modelling because of the extremely strong temperature inversion At the altitude of 1,880 m the temperature was 5 °3 C higher than at the altitude of 1,560 m and was the same as the temperature at the altitude of 770 m Also, the helicopter was unable to reach ARPA and turned off the line at an altitude of 2,2235 m leaving an altitude gap of 800 m without T, P, and e data On the night when the line 'Mees - Lighthouse' was measured there was no noticeable turbulence nor any anomalous temperature lapse rates In Table 2 the mean refractive numbers $\bar{N}_M$ are given as a function of polynoms with orders varying from 2 to 14

TABLE XIII-2

Order of Polynom	Mees - Lighthouse up	Mees - Lighthouse down
2	239 73	239 17
3	239 72	239 17
4	239 73	239 16
5	239 72	239 15
6	239 71	239 11
7	239 71	239 11
8	239 73	239 11
9	239 72	239 11
10	239 71	239 11
11	239 74	239 11
12	239 70	239 11
13	239 58	239 10
14	239 74	239 10

The mean values were $\bar{N}_M$ up = 239 71 (from numerical integration, $\bar{N}_N$ = 239 81) and $\bar{N}_M$ = 239 12 (from numerical integration, $\bar{N}_N$ = 239 16)

In the measurements of lines Puu Nianiau - ARPA, June 21, 1977 and July 28, 1977 and Puu Nianiau - LURE, July 28, 1977 helicopter could not be used to collect T, P, and e data because of the altitude and difficult topography In these cases two ground-based observation stations were set up, one at gravity calibration station #17 (H = 2,435 m) and the other at station #19 (H = 2,688 m), in addition to the stations located at the terminals of the lines Numerical integration and atmospheric modelling were established with the following results, given in Table 3

TABLE XIII-3

No	Line	$\bar{N}_N$	$\bar{N}_M$	$\Delta\bar{N}$	$\sigma_{\bar{N}_M}$
12	Puu Nianiau - ARPA, June	215 5	215 5	0 0	±0 4
12	Puu Nianiau - ARPA, July	211 7	211 8	+0 1	0 2
13	Puu Nianiau - LURE	211 1	211 1	0 0	0 3

The number of atmospheric samplings along lines flown by the helicopter varied between 40 and 60, depending on the length of the line It was found out that, especially in turbulent inversion conditions, the computed $\bar{N}$ - values started to scatter if more than 10-12 terms were used Therefore, the 6th order polynom was selected as a standard

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APPENDIX I

Computer Outputs and Plots for Line #5 Pier to ARPA and Line #6 Luke to Puu Nianiau

The Appendix includes the computer outputs for line #5 (Pier to ARPA) on June 20, 1977 and line #6 (Luke to Puu Nianiau) June 21, 1977 These are given as typical outputs and plots since many of the examples in the text have been drawn from these lines Each line was flown with the helicopter twice, once up and once down Data taken during the flight up are treated independently from data taken during the flight down so that two independent measurements are obtained for each line, resulting in a total of four line measurements in this Appendix The output pages for each of the four are independently numbered by the computer In the following a more detailed description is given for the first output of line #5, where the time on June 20, 1977 on "page 1" left column, starts at $1^{H}47^{M}0^{S}$

Page 1

The page gives all uncorrected atmospheric measurements at the pier and details on the instruments used The header "Pier to ARPA" indicates that the laser was located over the pier marker, and ranging performed to the reflectors over the ARPA marker The barometer correction for the particular barometer # and pressure was read from Fig III-4 and is part of the input data The coefficients for the psychrometer thermometers corrections are stored in the computer and used to calculate corrected wet and dry temperatures Zeroes in the time column indicate that no readings were taken Interpolated time values are given under "Reduced Atmospheric Data" Only data between *s are reduced and plotted in Figure AI-1 as a function of time The first * is the synchronization signal, indicating that the helicopter is on the line This signal is communicated to all field parties taking measurements Time differences, that might appear at the reduced data blocs, are wrist watch errors example page 1 indicates $1^{H}58^{M}00$ (at the pier or laser station and page 2 indicates $1^{H}59^{M}00$ (at the ARPA or reflector station) and the helicopter itself indicates $2^{H}00^{M}00$ on page 4 at the * value or on page 5, first value under "Reduced Helicopter Atmospheric Data "

The last line of page 1 gives the mean refractive number N(276 9) that is used as the base station value The other mean values are the ones used as initial values for the calculation of the helicopter altitudes during the flight up the line (Eq IV-9 to 12) starting at the "Elevation 2 28 m" of the marker also given in the header

Page 2

Page 2 contains atmospheric data similar to page 1 but taken at the reflector end of the line In addition, details of the reflector setup are given The reflector offset (of 40 mm) is the same for all our corner cubes used and therefore is a fixed value incorporated in the main program (Eq IV-5) The reduced data are plotted in Figure AI-2 versus time

Page 3

Page 3 gives the atmospheric data used to calibrate the helicopter probe

Pages 4, 5, 6

Page 4 and the first part of page 5 give uncorrected readings during the helicopter flight Zeroes in the time column indicate no readings taken, times for these rows in the "Reduced Helicopter

Atmospheric Data" are interpolated values Altitude readings (in km) in the uncorrected data are calculated values from the helicopter altimeter (originally in feet) that are only used for a check, but not in any further computation The "Vel" column (50 mph) is used for the pressure correction (Eq. (VI-6)) All data values between *s are taken for reduction

The "Reduced Helicopter Atmospheric Data" are presented on pages 5 and 6 and plotted in Figure AI-3 versus altitude Values in the columns Press, Temp, E are used to calculate the refractive number N that will be associated with the "Adjusted Alt " value (see Ch IV) The "N" and "Alt " values together with the values at the laser and the reflector stations are used to obtain the mean refractive number $\bar{N}$ (second term of Eq (V-7)) The mean refractive number appears at the end of the computer output for the line (page 9 last line = 239 52) The final line, page 6, "Multiplication Constant to Humphrey's Formula = 0 996377" gives the adjustment constant HC in Eq (IV - 10) (see also discussion in Ch IV)

Pages 7 and 8

The header on page 7 contains the setup parameters and correction for the laser above the marker The linearity correction (2 mm) was read from Fig III-3 (lower curve) to the nearest mm This correction is taken at the 9 3 (or 19 3) meter point of the basic 10-m length interval of the uncorrected range (first value at $1^{H}45^{M}$ is 30 289 378 m) "Uncorrected Range Data "

The "Range" column gives the direct readings from the laser instrument The frequency difference column indicates the measured difference to the nominal reference frequency of the laser Zero indicates no measurments are taken, but interpolated values are taken for reduction On different lines, the frequency difference might have been calculated as a function of battery voltage and the thermistor resistance (see Ch III and Fig III-2 and Eq (V-2)) Whenever the frequency was measured directly, it was used to make the line length corrections (Eq (V-1))

"Reduced Range Data in Meters"

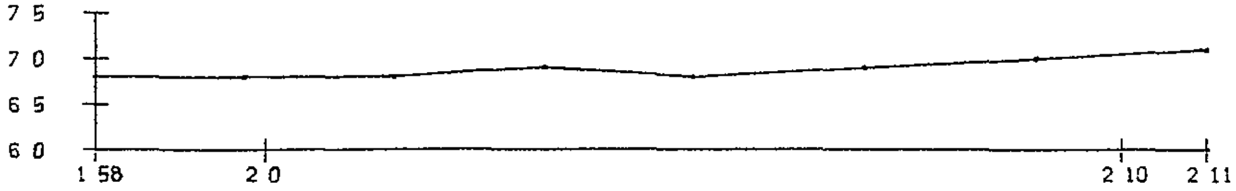
This bloc only shows reduced data calculated for those uncorrected data appearing between *s (that is during the time the helicopter was actually flying the line)

Frequency corrected line length values are those that include all geometric setup and instrument or reflector corrections and reduction to marker-to-marker distance (that is, the values of D_B in Eq (V-3) These values are plotted in Figure AI-4 The "Reduced Range" values in addition include correction for refractive index (Eq (V-6) and beam curvature (Eq (V-8))

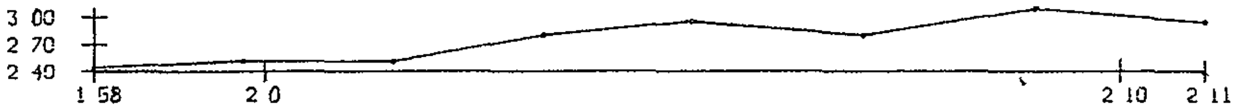
The mean values for these two different ranges are printed at the bottom of the page The "frequency corrected range" mean is essentially the raw data marker-to-marker distance and when compared to the mean corrected line length allows checks on the consistency of the refractive number determinations from one time to another In this example one would look for the comparative figures taken during the return flight of the line on the bottom of the next line measurement "pier to ARPA" where on that page 4, line 2 is "helicopter line data flying from ARPA " For this length measurement (page 8 and Figure AI-8) the "mean line length without atmospheric corrections = 30289,384 meters" compares to "the flight from the pier" value of 30289,392 meters The difference is due to the variation of the mean refractive number 239 52 for the flight up (from pier) and 239 24 for the flight down (from ARPA)

Similarly the data for the up and down flights from Luke to Puu Nianiau are given in the additional 2 sets of computer outputs and the plots Figure AI-9 through 16

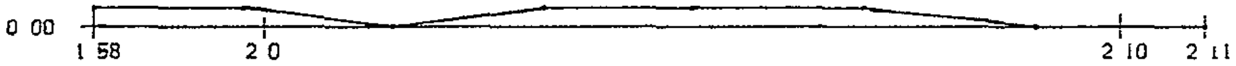
LINE #5 PIER TO ARPA   JUNE 20,1977
REFRACTIVE NUMBER 270.0 + GRAPH VALUE
PIER



VAPOR PRESSURE.20 0MB + GRAPH VALUE



BAROMETRIC PRESSURE 1017.5MB + GRAPH VALUE



DRY TEMPERATURE.23 0DEG. C + GRAPH VALUE

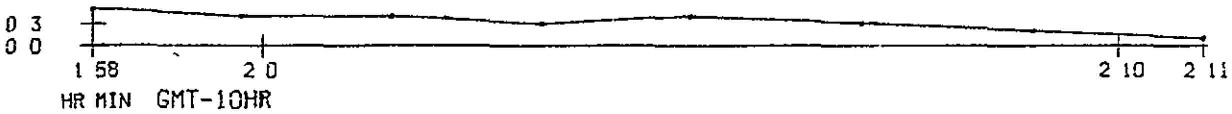
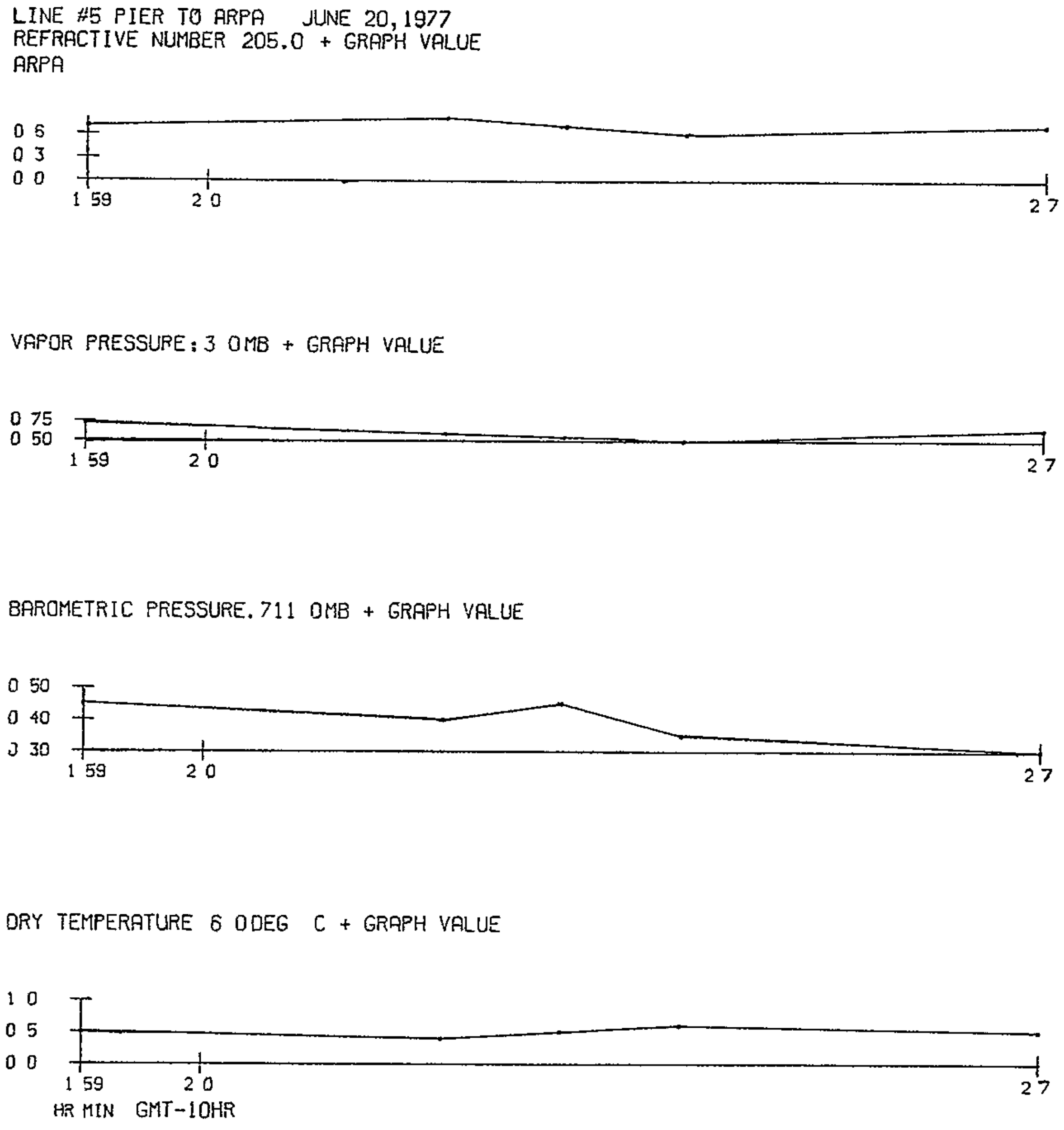


Fig AI-1



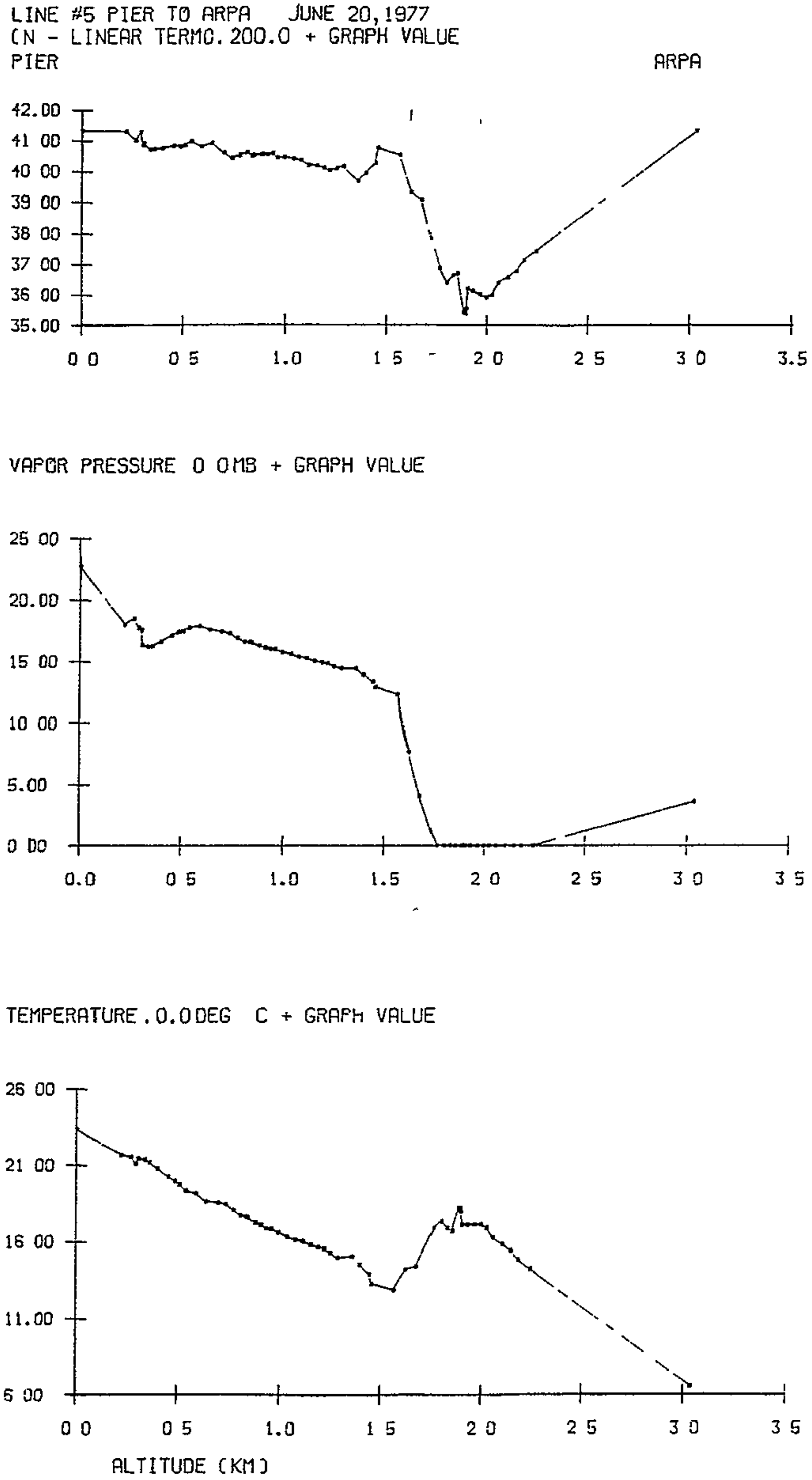
LINE #5 PIER TO ARPA JUNE 20, 1977
REFRACTIVE NUMBER 205.0 + GRAPH VALUE
ARPA

VAPOR PRESSURE: 3 0MB + GRAPH VALUE

BAROMETRIC PRESSURE. 711 0MB + GRAPH VALUE

DRY TEMPERATURE 6 0DEG C + GRAPH VALUE

Fig AI-2



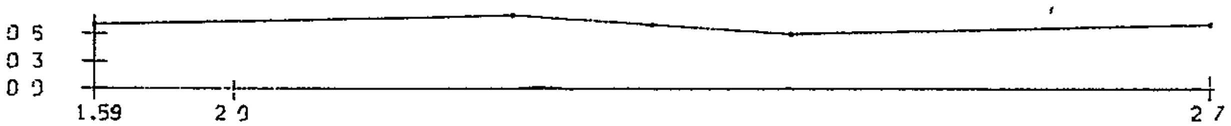
LINE #5 PIER TO ARPA JUNE 20,1977
(N - LINEAR TERMO. 200.0 + GRAPH VALUE

VAPOR PRESSURE 0 0MB + GRAPH VALUE

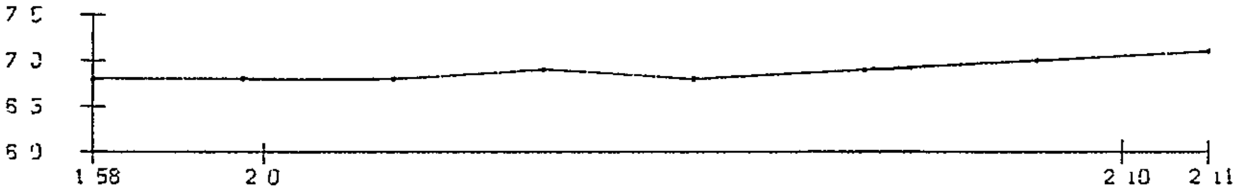
TEMPERATURE .0.0DEG C + GRAPH VALUE

Fig AI-3

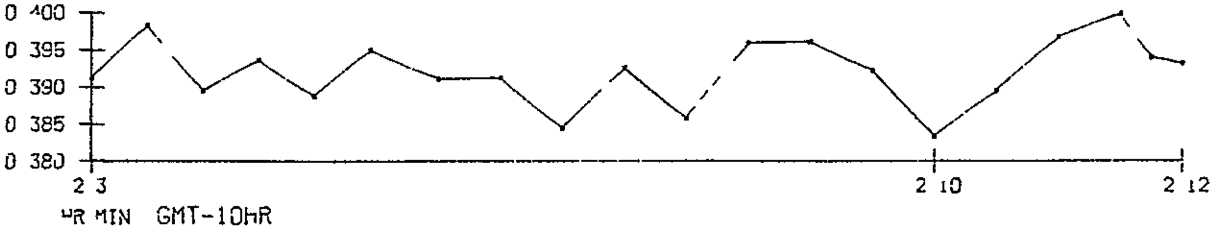
LINE #5 PIER TO ARPA JUNE 20,1977
REFRACTIVE NUMBER 205.0 - GRAPH VALUE
ARPA



LINE #5 PIER TO ARPA JUNE 20,1977
REFRACTIVE NUMBER 270.0 - GRAPH VALUE
PIER



UNCORRECTED RANGE.30289.0M - GRAPH VALUE



CORRECT DIST:30291.514M±0.001SD:M

(±0.004SD:Y)

Fig AI-4

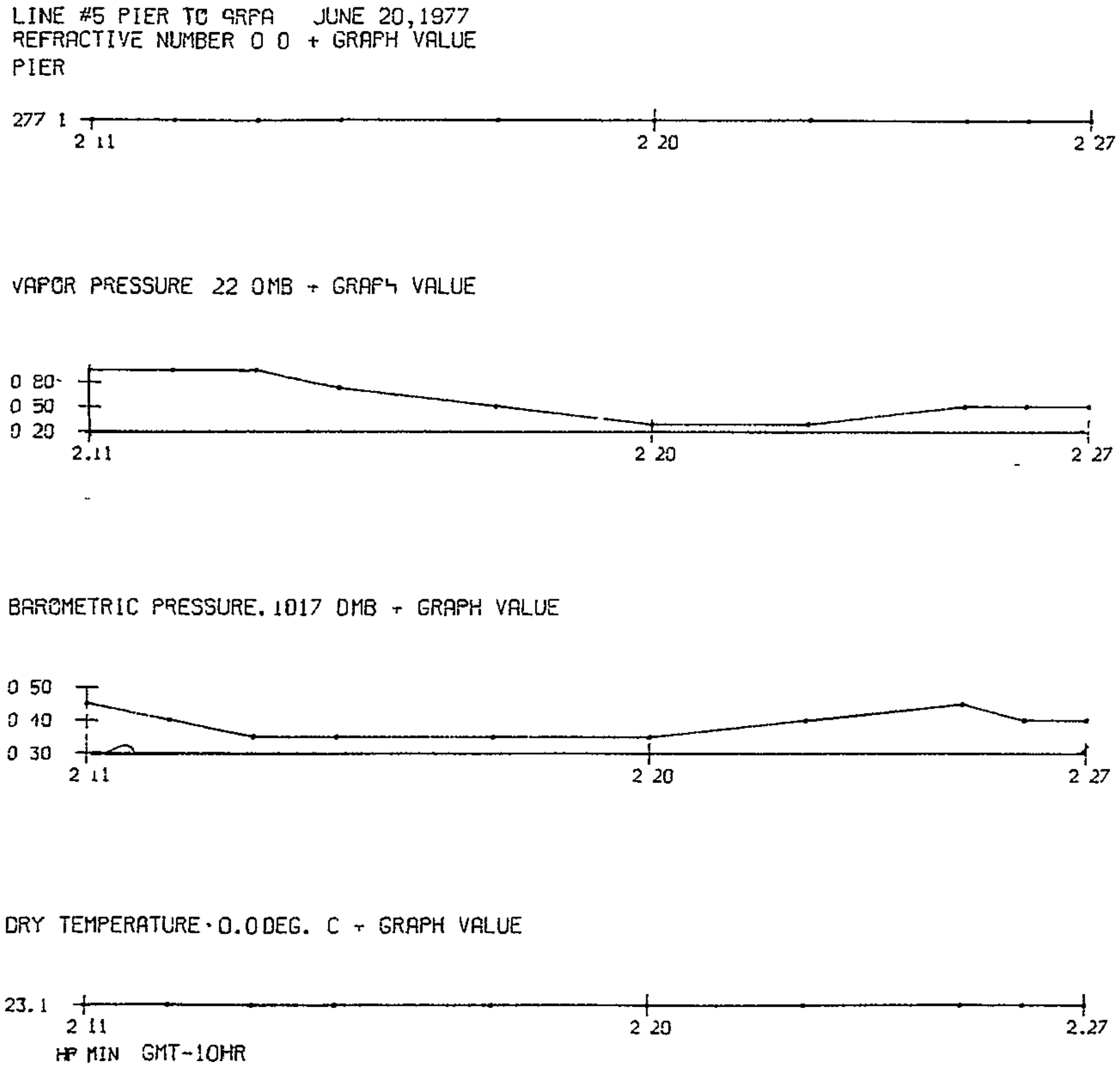

LINE #5 PIER TO ARPA JUNE 20,1977
REFRACTIVE NUMBER 0 0 + GRAPH VALUE
PIER
277 1
2 11
2 20
2 27
VAPOR PRESSURE 22 0MB + GRAPH VALUE
0 80
0 50
0 20
2.11
2 20
2 27
BAROMETRIC PRESSURE, 1017 0MB + GRAPH VALUE
0 50
0 40
0 30
2 11
2 20
2 27
DRY TEMPERATURE 0.0DEG. C + GRAPH VALUE
23.1
2 11
2 20
2.27
HR MIN GMT-10HR

Fig AI-5

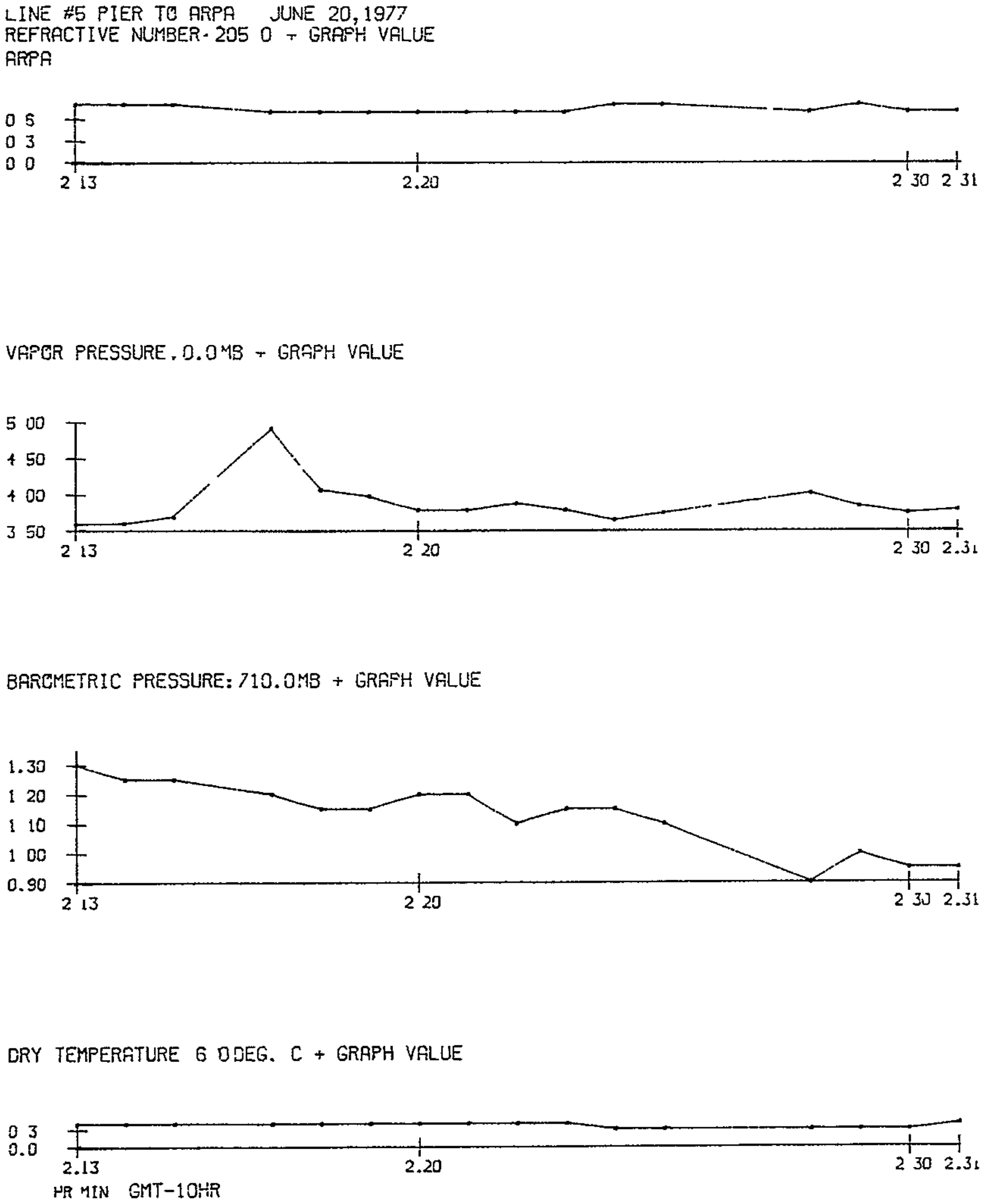
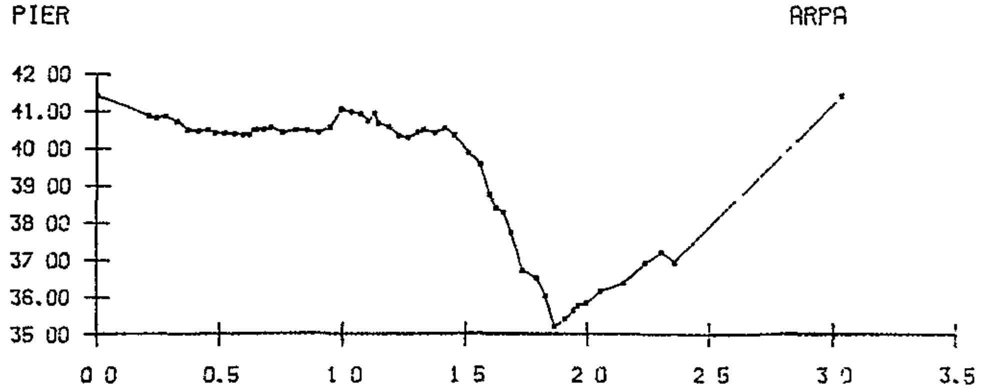
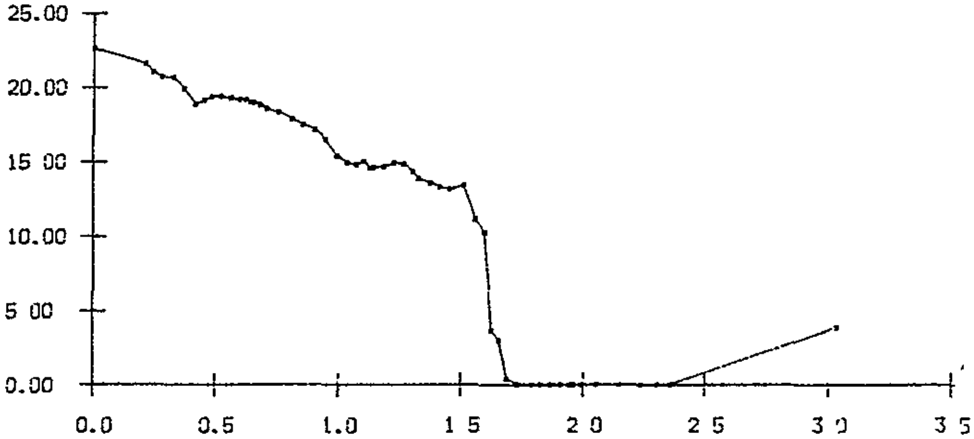

LINE #5 PIER TO ARPA JUNE 20,1977
REFRACTIVE NUMBER-205 0 + GRAPH VALUE
ARPA
0 6
0 3
0 0
2 13
2.20
2 30
2 31
VAPOR PRESSURE, 0.0 MB + GRAPH VALUE
5 00
4 50
4 00
3 50
2 13
2 20
2 30
2.31
BAROMETRIC PRESSURE: 710.0MB + GRAPH VALUE
1.30
1 20
1 10
1 00
0.90
2 13
2 20
2 30
2.31
DRY TEMPERATURE 6 0DEG. C + GRAPH VALUE
0 3
0.0
2.13
2.20
2 30
2.31
HR MIN GMT-10HR

Fig AI-6

LINE #5 PIER TO ARPA JUNE 20,1977
(N - LINEAR TERM)·200.0 + GRAPH VALUE



VAPOR PRESSURE.0.0MB + GRAPH VALUE



TEMPERATURE.0.0DEG. C + GRAPH VALUE

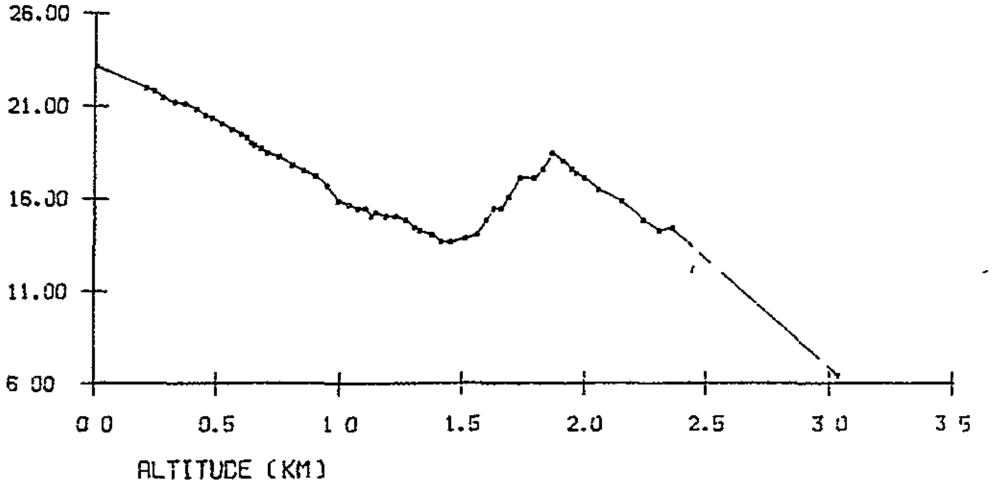
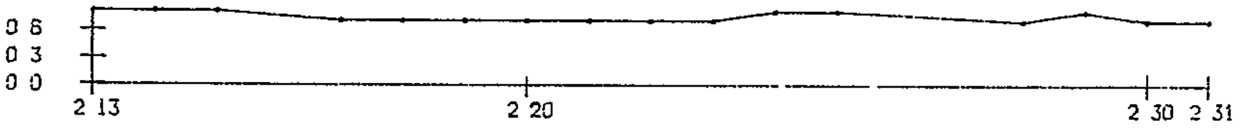
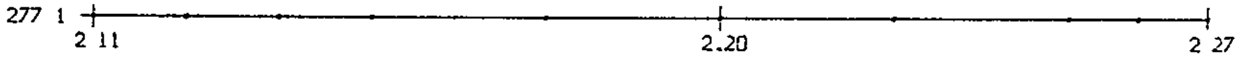


Fig. AI-7

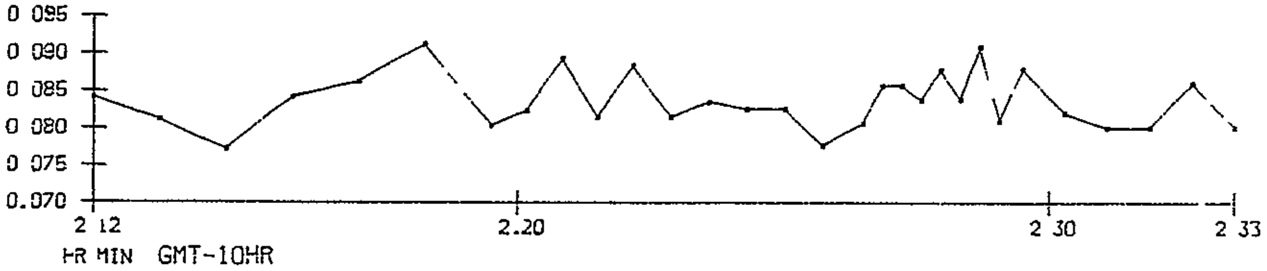
LINE #5 PIER TO ARPA   JUNE 20,1977
REFRACTIVE NUMBER·205 0 - GRAPH VALUE
ARPA



LINE #5 PIER TO ARPA   JUNE 20,1977
REFRACTIVE NUMBER 0.0 - GRAPH VALUE
PIER



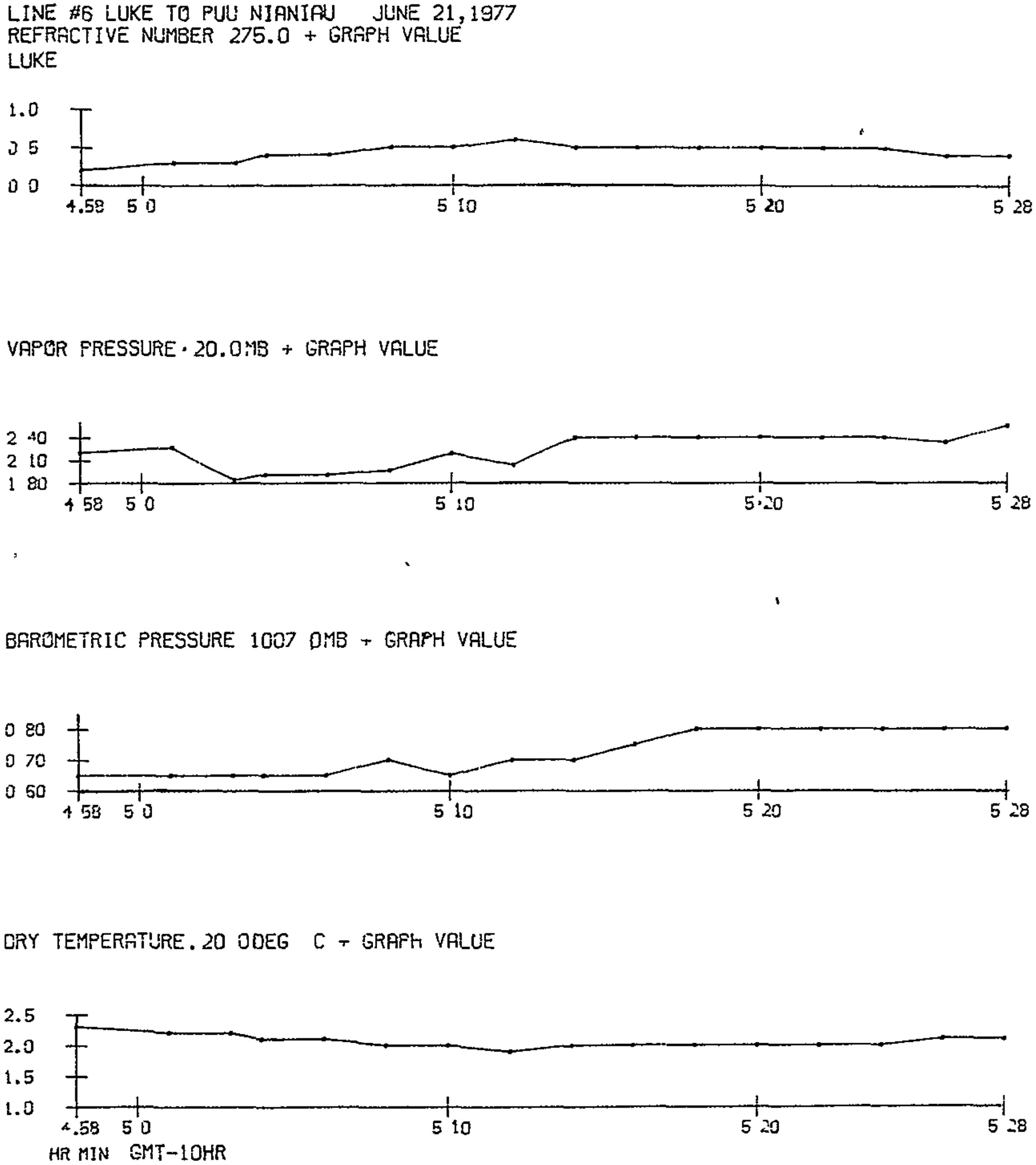
UNCORRECTED RANGE 30289 3M + GRAPH VALUE



CORRECT DIST:30291.514M±0.001SD:M

(±0.004SD:Y)

Fig AI-8



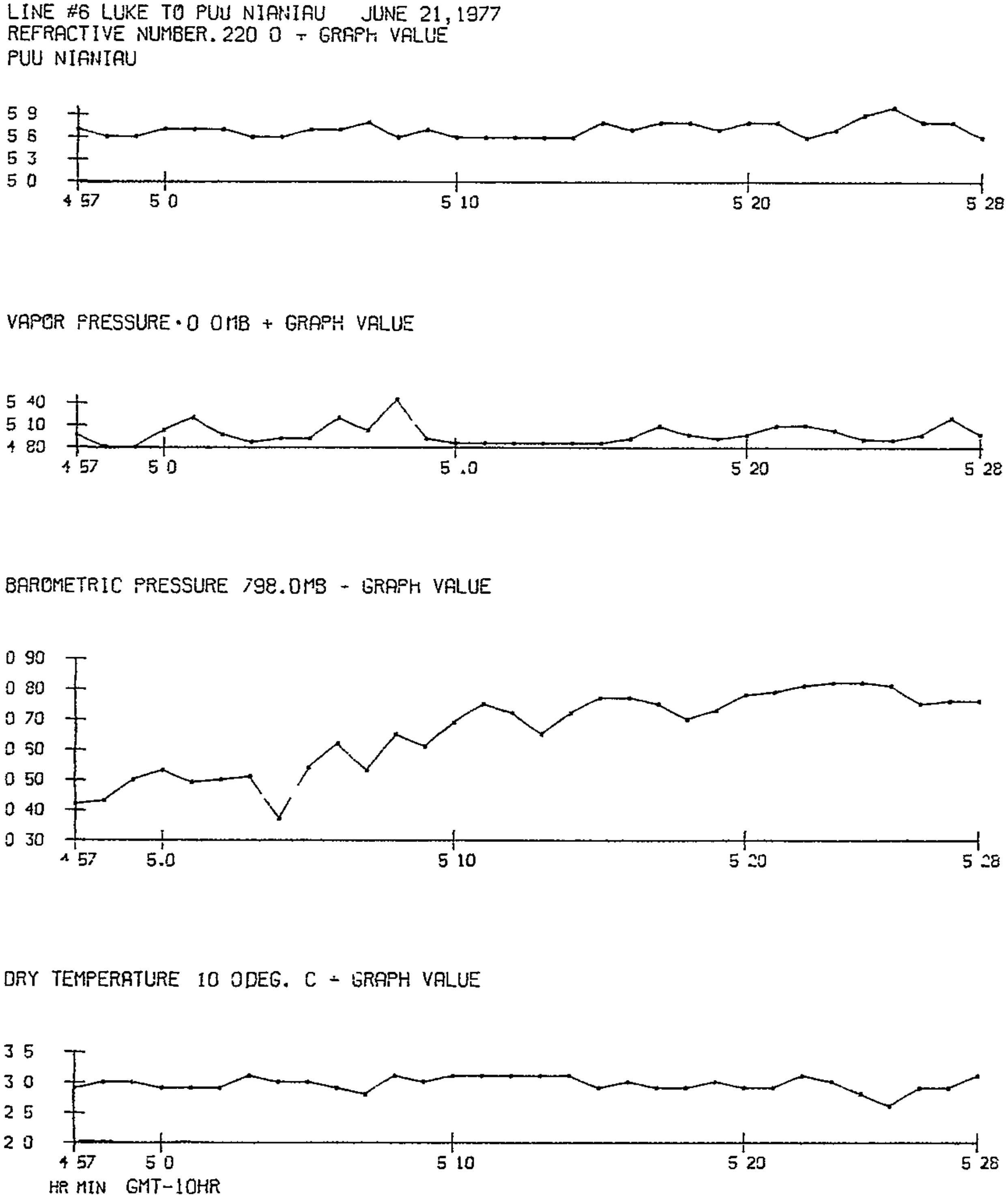
LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977
REFRACTIVE NUMBER 275.0 + GRAPH VALUE
LUKE

VAPOR PRESSURE 20.0MB + GRAPH VALUE

BAROMETRIC PRESSURE 1007 0MB + GRAPH VALUE

DRY TEMPERATURE 20 0DEG C + GRAPH VALUE

Fig AI-9



LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977
REFRACTIVE NUMBER.220 0 + GRAPH VALUE
PUU NIANIAU

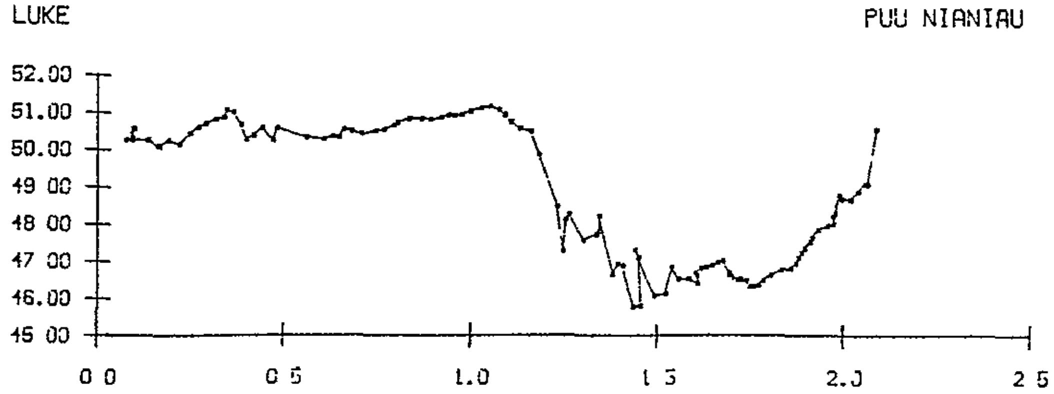
VAPOR PRESSURE·0 0MB + GRAPH VALUE

BAROMETRIC PRESSURE 798.0MB - GRAPH VALUE

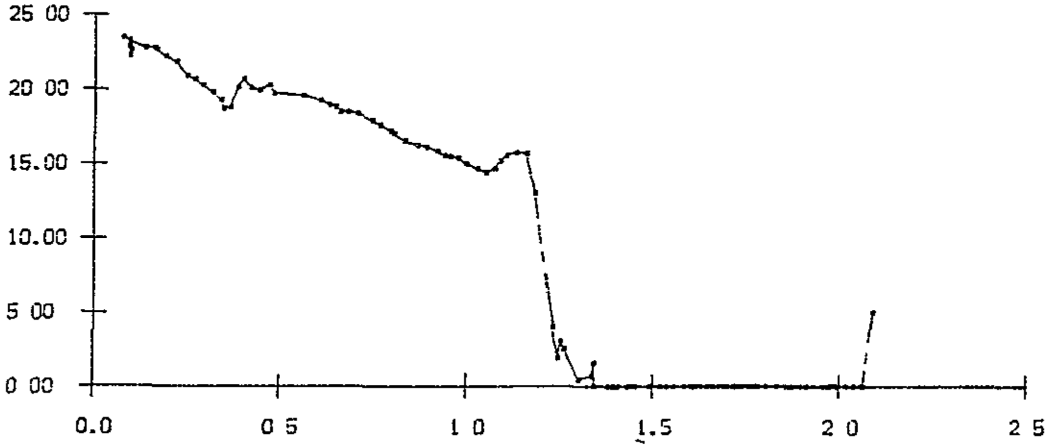
DRY TEMPERATURE 10 0DEG. C + GRAPH VALUE

Fig AI-10

LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977
(N - LINEAR TERM) 200 0 + GRAPH VALUE



VAPOR PRESSURE 0 0MB + GRAPH VALUE



TEMPERATURE.0.0DEG. C + GRAPH VALUE

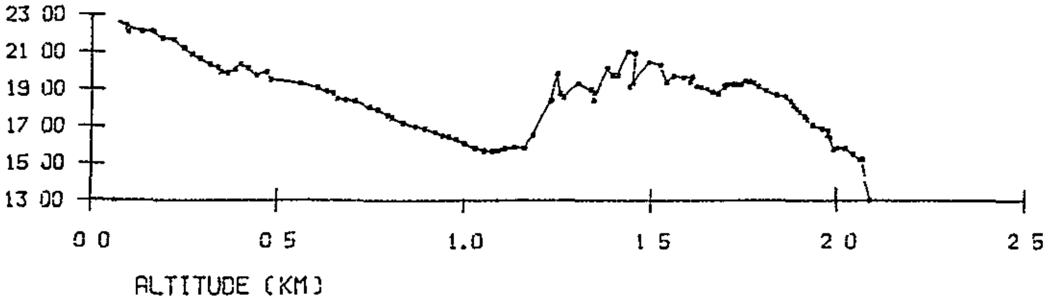
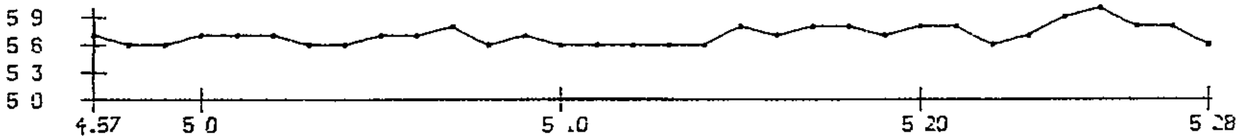
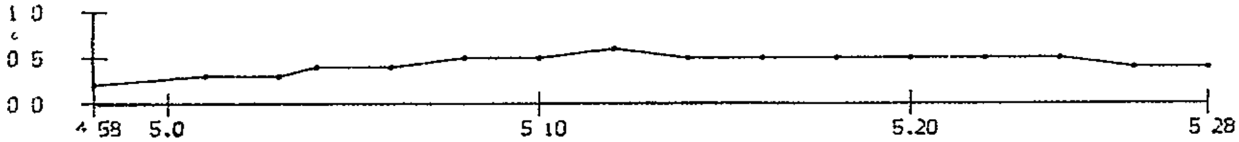


Fig. AI-11

LINE #6 LUKE TO PUU NIPNIAU JUNE 21,1977
REFRACTIVE NUMBER 220 0 - GRAPH VALUE
PUU NIPNIAU



LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977
REFRACTIVE NUMBER·275 0 - GRAPH VALUE
LUKE



UNCORRECTED RANGE 28841.2M + GRAPH VALUE

CORRECT DIST:28842.962M±0.001SD·M
(±0.003SD:Y)

Fig AI-12

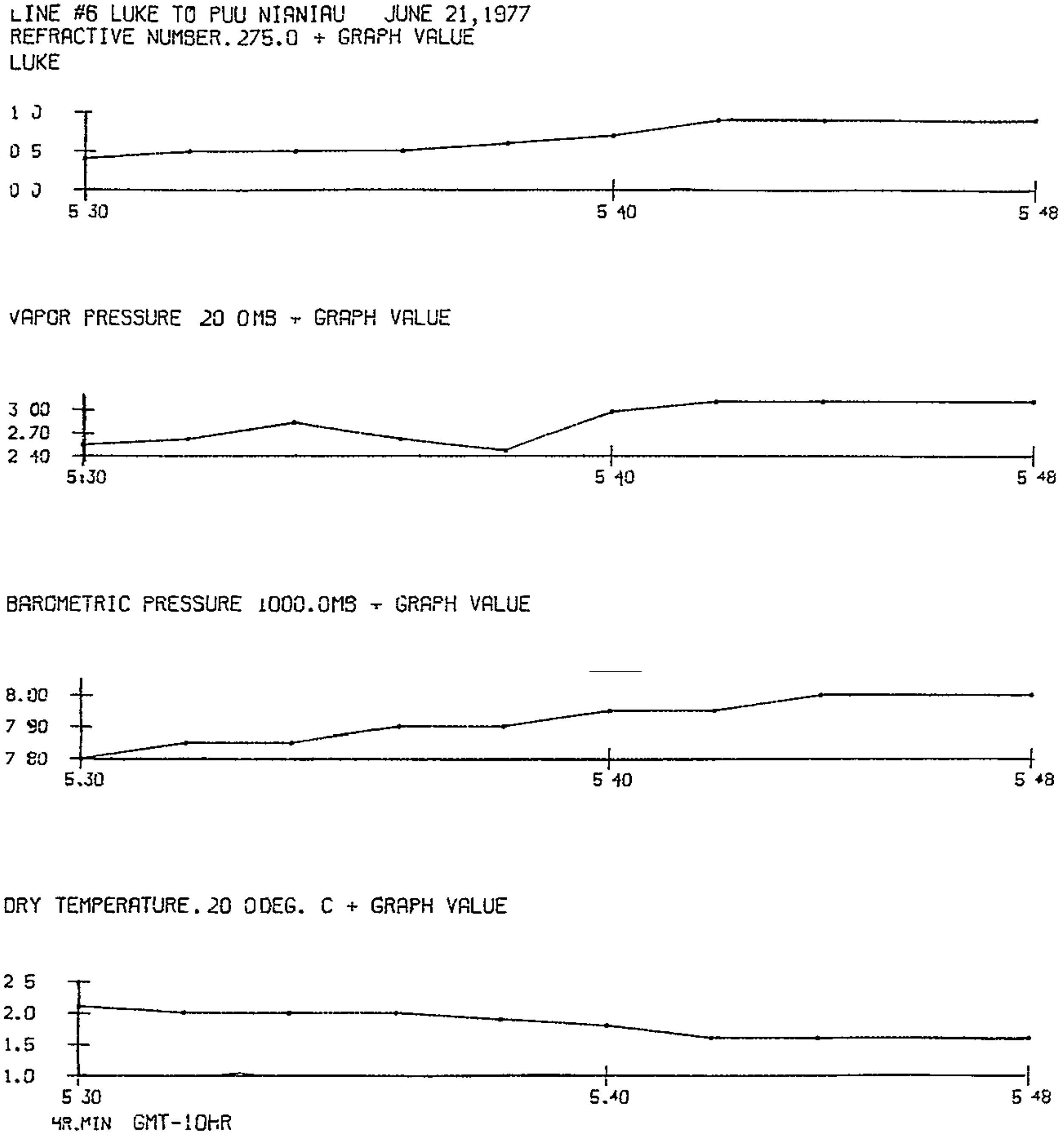
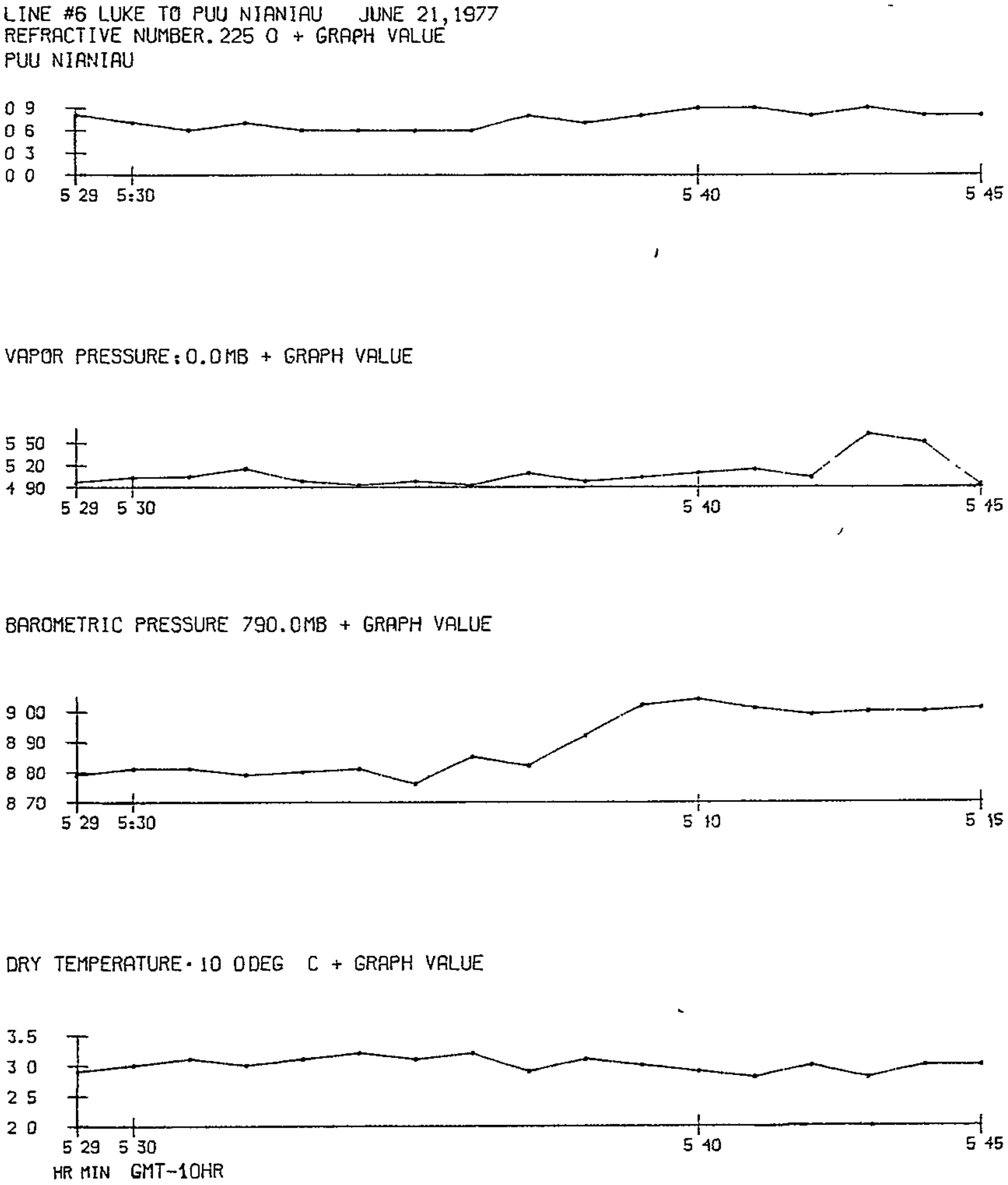

LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977
REFRACTIVE NUMBER.275.0 + GRAPH VALUE
LUKE
1.0
0.5
0.0
5:30
5:40
5:48
VAPOR PRESSURE 20.0MB + GRAPH VALUE
3.00
2.70
2.40
5:30
5:40
5:48
BAROMETRIC PRESSURE 1000.0MB + GRAPH VALUE
8.00
7.90
7.80
5:30
5:40
5:48
DRY TEMPERATURE.20.0DEG. C + GRAPH VALUE
2.5
2.0
1.5
1.0
5:30
5:40
5:48
HR.MIN GMT-10HR

Fig. AI-13



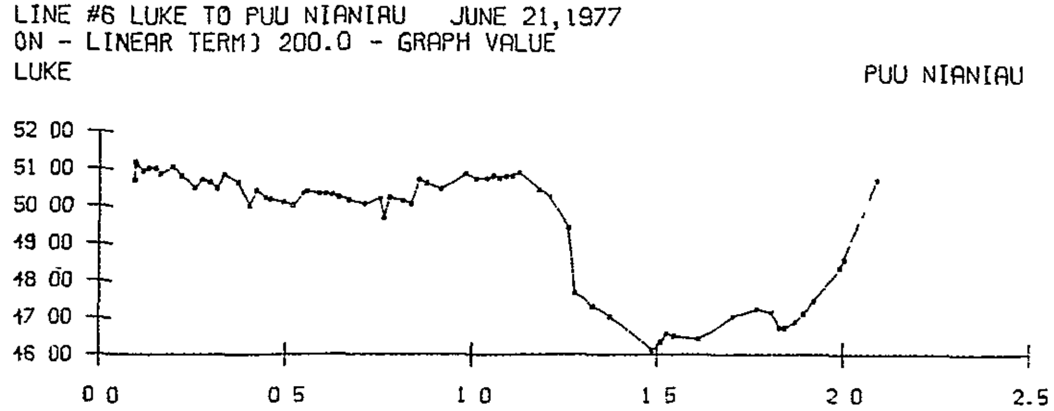
LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977
REFRACTIVE NUMBER. 225 0 + GRAPH VALUE
PUU NIANIAU

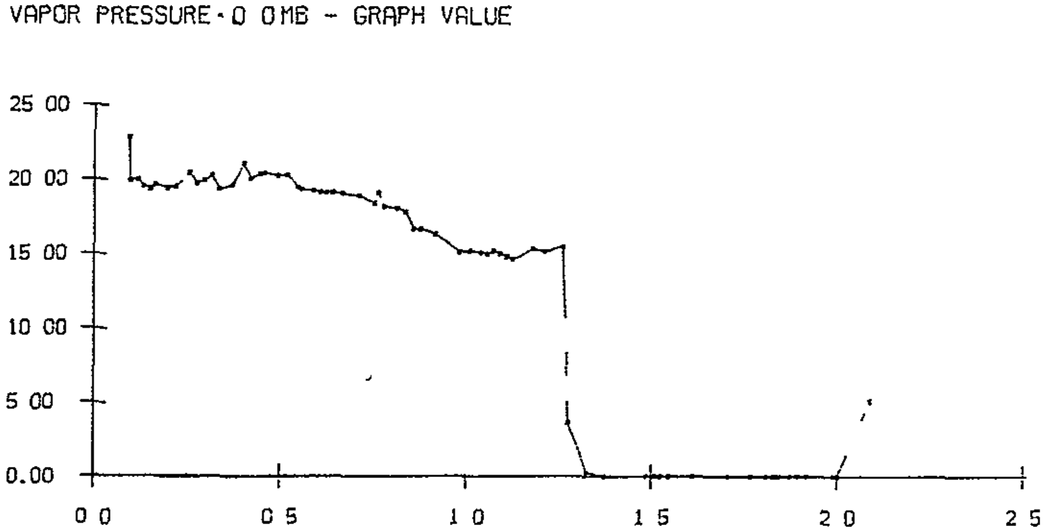
VAPOR PRESSURE: 0.0 MB + GRAPH VALUE

BAROMETRIC PRESSURE 790.0 MB + GRAPH VALUE

DRY TEMPERATURE· 10 0 DEG C + GRAPH VALUE

Fig AI-14


LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977
ON - LINEAR TERM) 200.0 - GRAPH VALUE


VAPOR PRESSURE·0 0 MB - GRAPH VALUE

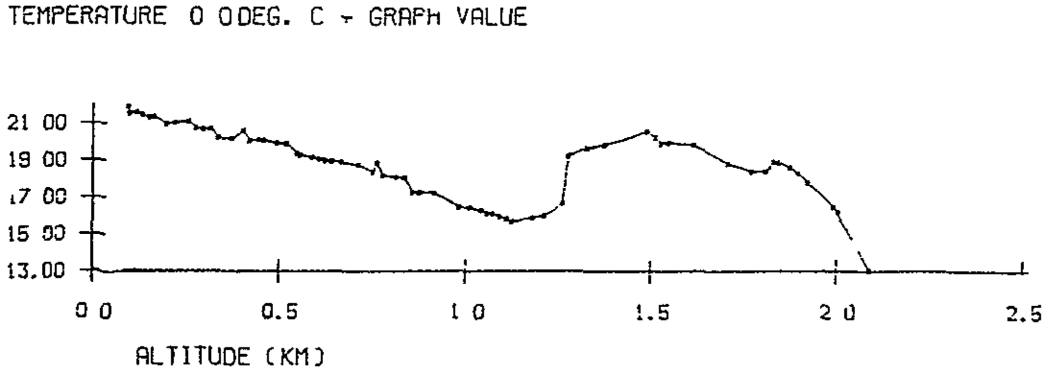
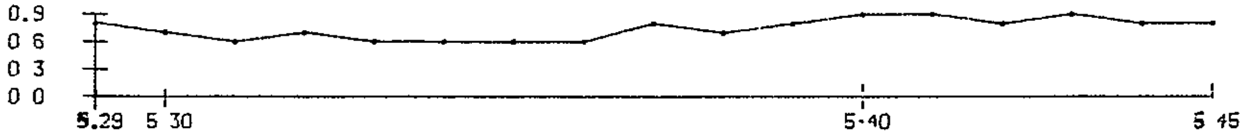
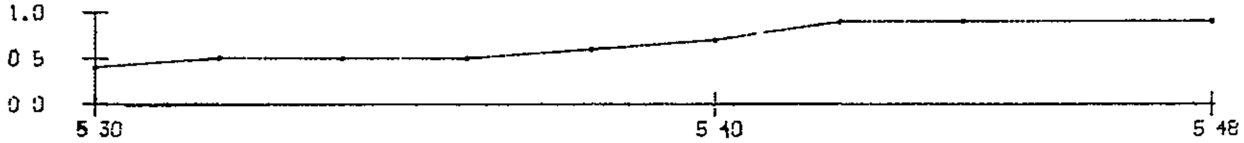

TEMPERATURE 0 0 DEG. C - GRAPH VALUE

Fig AI-15

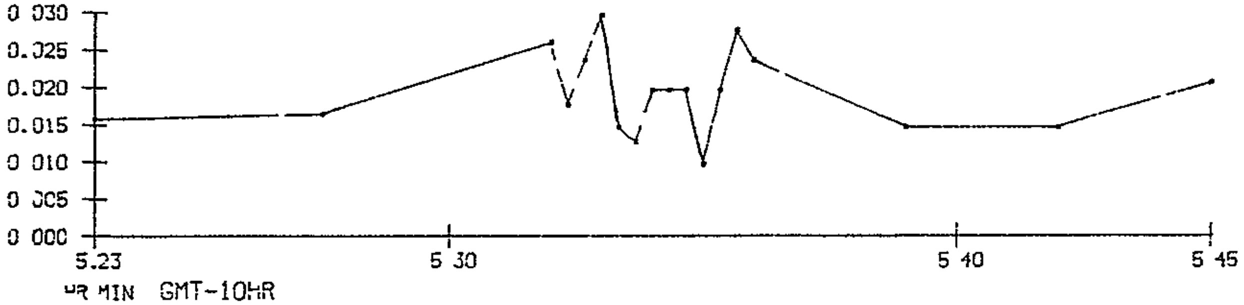
LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977
REFRACTIVE NUMBER 225 0 + GRAPH VALUE
PUU NIANIAU



LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977
REFRACTIVE NUMBER 275 0 - GRAPH VALUE
LUKE



UNCORRECTED RANGE 28841.2M + GRAPH VALUE



CORRECT DIST.28842.962M±0 001SD·M

[±0.005SD.Y]

Fig AI-16

LINE #5 PIER TO ARPA JUNE 20,1977

ATMOSPHERIC DATA TAKEN AT PIER
ELEVATION 2 28M
PSYCHROMETER #1 BAROMETER #1
BAROMETER CORRECTION. 0 05MBAR
OBSERVERS. LAURILA

UNCORRECTED DATA

TIME HR	MN	SEC	WET TEMP	DRY TEMP	BAROMETRIC PRES(MB)	COMMENTS
1	47	0	20 7	23 4	1017 60	
0	0	0	20 6	23 4	1017 60	
0	0	0	20 7	23 5	1017 55	
1	52	0	20 5	23 7	1017 55	
0	0	0	20 5	23 7	1017 55	
0	0	0	20 7	23 7	1017 50	
1	58	0	20 7	23 7	1017 50	
0	0	0	20 7	23 6	1017 50	
0	0	0	20 7	23 6	1017 45	
0	0	0	20 8	23 5	1017 50	
2	5	0	20 9	23 6	1017 50	
0	0	0	20 8	23 5	1017 50	
0	0	0	20 9	23 4	1017 45	
2	11	0	20 8	23 3	1017.45	

REDUCED ATMOSPHERIC DATA

TIME HR	MN	SEC	DRY TEMP	BAROMETRIC PRES(MB)	E	N	COMMENTS
1	58	0	23 5	1017 55	22 44	276 8	
1	59	45	23 4	1017 55	22 51	276 8	
2	1	30	23 4	1017 50	22 51	276.8	
2	3	15	23 3	1017 55	22 80	276 9	
2	5	0	23 4	1017 55	22 95	276 8	
2	7	0	23 3	1017 55	22 80	276 9	
2	9	0	23 2	1017 50	23 09	277 0	
2	11	0	23 1	1017 50	22 94	277 1	
MEANS			23 3	1017 53	22 76	276 9	

```
LINE #5 PIER TO ARPA   JUNE 20,1977

REFLECTOR ATMOSPHERIC DATA TAKEN AT ARPA
ELEVATION   3033.51M
HEIGHT TO THE TOP OF THE TRIBRACH   520 MM
HEIGHT FROM THE TOP OF THE TRIBRACH
  TO THE CENTER OF THE REFLECTORS  287 MM
TOTAL REFLECTOR HEIGHT ABOVE THE MARKER   807 MM
NUMBER OF REFLECTORS  21
ECCENTRICITY   0MM
PSYCHROMETER #3    BAROMETER #5
BAROMETER CORRECTION   0.75MBAR
OBSERVERS  WOLFE

UNCORRECTED DATA

  TIME      WET     DRY   BAROMETRIC   COMMENTS
HR MN SEC  TEMP    TEMP    PRES(MB)

 1 49  0    1.4     6.9     710.60     CLEAR, WINDY  40 MPH WIND
 0  0  0   -0.2     7.0     710.55     W/GUSTS UP TO MAYBE 50 MPH
 0  0  0   -0.4     7.0     710.55
 1 56  0    0.5     7.0     710.65
 0  0  0    0.6     6.9     710.70*
 2  2  0    0.4     6.8     710.65     REWOUND PSYCHROMETER
 2  3  0    0.4     6.9     710.70
 2  4  0    0.4     7.0     710.60
 2  7  0    0.5     6.9     710.55*    R/R BATTERY, REWOUND PSY

REDUCED ATMOSPHERIC DATA

  TIME      DRY   BAROMETRIC    E       N      COMMENTS
HR MN SEC  TEMP    PRES(MB)

 1 59  0    6.5    711.45     3.73   205.7
 2  2  0    6.1    711.40     3.59   205.8   REWOUND PSYCHROMETER
 2  3  0    6.5    711.45     3.55   205.7
 2  4  0    6.6    711.35     3.50   205.6
 2  7  0    6.5    711.30     3.64   205.7   R/R BATTERY, REWOUND PSY

MEANS       6.5    711.39     3.60   205.7
```

```
LINE #5 PIER TO ARPA   JUNE 20,1977

INITIAL  CALIBRATION OF THE HELICOPTER HYGRISTOR AT PIER
PSYCHROMETER #4     BAROMETER #2
BAROMETER CORRECTION  -0.25 MBAR
CALIBRATION RESISTANCE OF THE HYGRISTOR   95 0 KOHM
ZERO PRESSURE FREQUENCY OF DIGIQUARTZ  39303 70 HZ
OBSERVER  SCHENCK

UNCORRECTED DATA

  TIME      WET      DRY      THERM     HYGRIS BAROMETRIC  DIGIQTZ  COMMENTS
HR MN SEC TEMP     TEMP     (KOHM)    (KOHM)   PRES(MB)   FREQ (HZ)

 1 29   0  19.9     23 9     16 06      466 0   1016 65     35306 7
0   0   0  19 9     23 9     16 07      469 0   1016 65     35306 8
0   0   0  20 0     23 9     16 07      486 0   1016 70     35306 8
0   0   0  20 0     23.8     16 08      508 0   1016 70     35306 7
 1 36   0  20 0     23 8     16 07      504 0   1016 70     35306 8

REDUCED DATA

  TIME      DIGITAL DIGIQTZ  DRY  THER     E      E
HR MN SEC   PRESS    PRESS   TEMP TEMP   GRND   HELI.

 1 29   0  1016 40 1016 31  24 1 23.1  20 60 19 88
 1 30 45   1016 40 1016 29  24 1 23 1  20 60 19 88
 1 32 30   1016 45 1016 29  24 1 23 1  20.82 20 07
 1 34 15   1016 45 1016 31  24 0 23 1  20 89 20 27
 1 36   0  1016 45 1016 29  24 0 23 1  20 89 20 26
```

LINE #5 PIER TO ARPA JUNE 20, 1977

HELICOPTER LINE DATA. FLYING FROM PIER

UNCORRECTED DATA

TIME			ALT	VEL	THERM	DIGIQTZ	HYGRIS	COMMENTS
HR	MN	SEC	(KM)	MPH	KOHM	FREQ (HZ)	KOHM	
2	0	0	0.152	50	16 63	35414 1	450 0*	
0	0	0	0 000	0	16 68	35436 9	517 0	
0	0	0	0 000	0.	16 87	35448.1	492 0	
0	0	0	0 000	0	16 72	35453 8	433 0	
0	0	0	0 000	0	16 74	35156 1	346 0	
0	0	0	0 000	0	16 75	35470 1	338 0	
0	0	0	0 000	0	16 83	35480 4	356 0	
0	0	0	0 000	0	16 99	35499 6	414 0	
0	0	0	0.000	0	17 21	35525 0	524 0	
0	0	0	0 457	50	17 33	35540.9	610 0	
0	0	0	0 000	0	17 43	35550 9	664 0	
0	0	0	0 000	50	17 60	35565 2	814 0	
2	3	0	0 000	50	17 69	0 0	0 0	
0	0	0	0 000	50	17 92	35611 6	1005 0	
0	0	0	0 000	50	17 96	35638 2	984 0	
0	0	0	0 000	50	18 00	35655 7	969 0	
0	0	0	0 000	50	18 17	35672 7	981 0	
0	0	0	0 762	50	18 33	35688 4	1005 0	
0	0	0	0 000	50	18 36	35699 8	1024.0	
0	0	0	0 000	50	18 39	35702 9	1027 0	
0	0	0	0 000	50	18 54	35720 4	1072 0	
0	0	0	0 853	50	18 61	35731 7	1066 0	
0	0	0	0 000	50	18 72	35742 5	1129 0	
0	0	0	0 000	50	18 72	35752 7	1127 0	
0	0	0	0 945	50	18 84	35768 1	1131 0	
0	0	0	0 000	50	18 96	35787 5	1182 0	
0	0	0	0 000	50	19 06	35804 2	1180 0	
0	0	0	0 000	50	19 10	35820 8	1167 0	
0	0	0	1 097	50	19 21	35837 9	1167 0	
0	0	0	0 000	50	19 29	35853 7	1191 0	
0	0	0	0 000	50	19 33	35865 9	1191 0	
0	0	0	1 189	50	19.47	35879 1	1210 0	
0	0	0	0 000	50	19 62	35894 2	1276 0	
0	0	0	0 000	50	19 57	35925 1	1226 0	
0	0	0	0 000	50	19 81	35941 2	1223 0	
0	0	0	1 341	50	0 00	35960 8	1230 0	
0	0	0	0 000	50	20 50	35966 0	1319 0	
0	0	0	0.000	50	20 70	36011 5	1138 0	
0	0	0	0 000	50	20 00	36034 8	172 0	
0	0	0	0 000	50.	19 90	36055 9	75 0	
0	0	0	1 676	50	18 70	36091 0	24 0	
0	0	0	0 000	50	18 50	36105 5	24 0	
0	0	0	0 000	50	18 70	36117 5	26 0	
0	0	0	0 000	50	18 80	36126 7	20 0	
2	12	0	0 000	50	18 10	36138 5	17 0	
0	0	0	1 737	50	18 16	36142 3	17 0	
0	0	0	0 000	50	18 20	36143 5	19 0	
0	0	0	0 000	50	18 60	36146 5	19 0	
2	13	0	1 829	50	18 60	36156 3	18 0	
0	0	0	0 000	50	18 60	36170 4	18 0	
0	0	0	0 000	50	18 60	36182 7	18 0	
0	0	0	1 890	50	18 70	36193 1	18 0	
0	0	0	0 000	50	19 00	36235 8	18 0	

```
LINE #5 PIER TO ARPA   JUNE 20,1977

UNCORRECTED DATA

  TIME       ALT.   VEL  THERM     DIGIQTZ   HYGRIS  COMMENTS
HR MN SEC   (KM)   MPH    KOHM    FREQ (HZ)   KOHM

 0  0  0   0 .000   50    19 20    36224 0     19 0
 0  0  0   1 981    50    19 40    36239.7     19 0
 0  0  0   0 000    50    19 70    36254 0     21 0  TURBULENCE
 2 14 30   2 134    50.   20 00    36276 8     21 0* TURBULENCE

REDUCED HELICOPTER ATMOSPHERIC DATA

  TIME     ADJUSTED  PRESS    TEMP     E       N      COMMENTS
HR MN SEC ALT (KM)    (MB)

 2  0  0   0 21953   992 44   21 7   17 97   271 8
 2  0 15   0 26755   986 96   21 5   18.49   270 4
 2  0 30   0 29122   984 27   21 1   17.72   270 1
 2  0 45   0.30330   982 90   21.4   17 53   269 4
 2  1  0   0 30818   982.35   21 4   16 32   269 3
 2  1 15   0 33792   978 98   21 4   16 17   268 4
 2  1 30   0 35988   976 50   21 2   16 24   267 9
 2  1 45   0 40093   971 87   20.8   16 59   267 0
 2  2  0   0.45551   965 75   20 3   17.09   265.8
 2  2 15   0 48983   961 91   20 0   17 40   264 9
 2  2 30   0 51148   959 50   19 7   17 47   264 5
 2  2 45   0 54251   956 05   19 3   17 76   263 9
 2  3  0   0 59309   950.45   19 1   17 88   262 5
 2  3 16   0 64393   944 84   18.6   17 59   261 4
 2  3 32   0 70258   938 40   18 5   17 43   259 7
 2  3 48   0 74141   934 17   18 4   17 28   258 6
 2  4  4   0 77928   930 05   18 1   16 90   257 8
 2  4 20   0 81437   926.24   17.7   16.58   257 1
 2  4 36   0 83993   923 48   17 6   16 56   256 4
 2  4 52   0 84690   922 73   17 6   16 50   256 3
 2  5  8   0 88631   918 48   17 2   16 27   255 4
 2  5 24   0 91184   915 74   17 1   16 09   254.7
 2  5 40   0.93631   913 12   16 9   15 99   254 2
 2  5 56   0 95948   910 64   16 9   15 99   253 5
 2  6 12   0 99458   906 90   16.6   15 73   252 7
 2  6 28   1 03898   902 19   16 3   15 58   251 6
 2  6 44   1 07739   898 12   16 1   15 36   239 7
 2  7  0   1 11573   894 09   16 1   15 25   249 6
 2  7 16   1 15541   889 92   15 8   15 02   248 7
 2  7 32   1 19233   886 07   15 7   14 90   247 7
 2  7 48   1 22077   883 10   15 6   14 82   247 0
 2  8  4   1 25175   879 88   15 3   14 58   246 3
 2  8 20   1 28731   876 20   15 0   14 40   245 6
 2  8 36   1 36056   868 66   15 1   14 41   243 4
 2  8 52   1 39898   864 72   14 5   13 90   242 7
 2  9  8   1 44591   859 93   13 9   13 32   242 0
 2  9 24   1 45838   858 66   13 3   12 90   242 2
 2  9 40   1 56814   847 53   12 9   12 29   239 3
 2  9 56   1 62501   841 82   14 2    7 64   236 8
 2 10 12   1 67692   836 65   14 4    4 06   235 3
 2 10 28   1 76432   828.04   16 9    0 00   231 1
 2 10 44   1 80087   824 48   17 3    0 00   229 7
 2 11  0   1 83126   821 53   16 9    0 00   229 3
 2 11 16   1 85161   819 27   16 7    0 00   228 8
 2 12  0   1 88473   816 37   18 2    0 00   226 8
```

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LINE #5 PIER 10 ARPA   JUNE 20,1977

REDUCED HELICOPTER ATMOSPHERIC DATA

  TIME      ADJUSTED  PRESS     TEMP      E        N      COMMENTS
HR MN SEC ALT (KM)    (MB)

 2 12 15   1 89448   815 44   18 2    0 00   226 5
 2 12 30   1 89756   815 14   18 0    0 00   226 6
 2 12 45   1 90525   814.40   17.1    0 00   227 1
 2 13  0   1 93040   811 99   17 1    0 00   226 4
 2 13 11   1 96672   808 53   17 1    0 00   225 5
 2 13 22   1 99854   805 50   17 1    0 00   224 6
 2 13 33   2 02554   802 94   16 9    0 00   224 1
 2 13 44   2 05860   799 81   16 3    0 00   223.7
 2 13 55   2 10613   795 32   15 8    0 00   222 7
 2 14  6   2 14731   791 45   15 4    0 00   222 0
 2 14 17   2 18495   787 93   14 8    0 00   221 5   TURBULENCE
 2 14 30   2 24522   782 30   14 2    0 00   220 3   TURBULENCE

MULTIPLICATION CONSTANT TO HUMPHREYS FORMULA= 0 996377
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LINE #5 PIER TO ARPA   JUNE 20,1977

RANGE DATA TAKEN AT PIER
HEIGHT TO THE TOP OF THE TRIBRACH  1125.MM
TOTAL LASER HEIGHT ABOVE THE MARKER. 1365.MM
ECCENTRICITY   0MM
DAYLIGHT FILTER  OUT
A 137 MM OFFSET HAS BEEN DIALED INTO THE INSTRUMENT
LINEARITY CORRECIION·   2 MM
OBSERVERS    LAURILLA,HARRIS

UNCORRECTED RANGE DATA

  TIMF       RANGE      FREQ   BATTERY THFRM        COMMENTS
HR MN SEC  (METERS)    DIFF   VOLTAGE (KOHM)

 1 45  0   30289 378    4 1   12 380   0.000
 0  0  0   30289 383    3 9    0 000   0 000
 0  0  0   30289 390    0 0    0.000   0 000
 0  0  0   30289 381    0 0    0.000   0 000
 1 46  0   30289 385    0 0    0.000   0 000
 0  0  0   30289 381    0 0    0 000   0 000
 1 49  0   30289 380    0 0    0 000   0 000
 0  0  0   30289 373    0.0   12.360   0 000
 0  0  0   30289 381    0 0    0 000   0 000
 0  0  0   30289 382    0 0    0 000   0 000
 0  0  0   30289 385    0 0    0 000   0.000
 0  0  0   30289 370    0 0    0 000   0 000
 0  0  0   30289 378    0 0    0 000   0 000
 0  0  0   30289 384    0 0    0 000   0 000
 0  0  0   30289 384    0 0    0.000   0 000
 0  0  0   30289 379    0.0    0.000   0 000  -.2 C WET
 0  0  0   30289 380    0 0    0.000   0 000  7 C DRY
 0  0  0   30289 382    0 0    0 000   0.000  SLOW
 0  0  0   30289 374    0 0    0 000   0 000
 0  0  0   30289 379    0 0    0 000   0 000
 0  0  0   30289 380    0 0    0 000   0 000
 0  0  0   30289 378    0 0    0 000   0 000
 1 55 30   30289 369    0 0    0 000   0 000
 0  0  0   30289 375    0 0    0 000   0 000
 0  0  0   30289 381    0 0    0 000   0 000
 1 56 50   30289 377    0 0    0 000   0 000
 0  0  0   30289 379    0 0    0 000   0 000
 0  0  0   30289 370    0 0    0.000   0 000
 0  0  0   30289 374    0 0    0 000   0 000
 0  0  0   30289 362   -0 6    0 000   0 000
 0  0  0   30289 367    0.0    0 000   0 000  READY
 0  0  0   30289 373    0 0    0 000   0 000
 0  0  0   30289 373    0 0    0 000   0 000
 0  0  0   30289 375    0.0    0 000   0 000
 0  0  0   30289 382    0.0    0 000   0 000
 0  0  0   30289 367    0 0    0 000   0 000
 2  2 45   30289 372    0 0   12.340   0 000
 0  0  0   30289 376    0 0    0 000   0 000* R
 0  0  0   30289 383    0 0    0 000   0 000
 0  0  0   30289 374    0 0    0 000   0 000
 0  0  0   30289 378    0 0    0 000   0 000
 0  0  0   30289 373    0 0    0 000   0 000
 0  0  0   30289 379    0 0    0 000   0 000
 2  6  0   30289 375    0 0    0.000   0 000
 0  0  0   30289 375    0 0    0 000   0 000
 0  0  0   30289 368    0 0    0 000   0 000
```

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LINE #5 PIER TO ARPA   JUNE 20,1977

UNCORRECTED RANGE DATA

  TIME         RANGE       FREQ    BATTERY THERM        COMMENTS
HR MN SEC   (METERS)     DIFF.   VOLTAGE (KOHM)

 0   0   0   30289 376     0 0    0.000    0 000
 0   0   0   30289 369     0 0    0 000    0 000
 0   0   0   30289 379     0 0    0 000    0 000
 0   0   0   30289 379     0 0    0 000    0 000
 0   0   0   30289 375     0 0    0 000    0 000
 0   0   0   30289 366     0 0    0.000    0 000
 0   0   0   30289 372     0 0    0.000    0 000
 0   0   0   30289 379     0 0    0 000    0 000
 2  11  30   30289 382     0 0   12 320    0 000
 0   0   0   30289.376     0 0    0 000    0 000
 2  12   0   30289 375    -2 7   12 310    0 0004

REDUCED RANGE DATA IN METERS

  TIME       FREQUENCY      REDUCED    COMMENTS
HR MN SEC   CORRECTED       RANGE

 2   3  12   30289 391    30291 513   R
 2   3  39   30289.398    30291.520
 2   4   6   30289 389    30291 511
 2   4  33   30289.394    30291.515
 2   5   0   30289 389    30291 510
 2   5  27   30289 395    30291.517
 2   6   0   30289 391    30291.513
 2   6  30   30289 391    30291 513
 2   7   0   30289 384    30291 506
 2   7  30   30289 393    30291 514
 2   8   0   30289 386    30291 507
 2   8  30   30289 396    30291 518
 2   9   0   30289 396    30291 518
 2   9  30   30289 392    30291 514
 2  10   0   30289 383    30291 505
 2  10  30   30289 390    30291 511
 2  11   0   30289 397    30291.518
 2  11  30   30289 400    30291 521
 2  11  45   30289 394    30291 516
 2  12   0   30289 393    30291.515

MEAN LINE LENGTH WITHOUT ATMOSPHERIC CORRECTIONS=  30289.392 METERS
MEAN CORRECTED LINE LENGTH=  30291 514 METERS
STANDARD DEVIATION=  0044 METERS
STANDARD DEVIATION OF THE MEAN=  0010 METERS
MEAN REFRACTIVE NUMBER= 239 52
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LINE #5 PIER TO ARPA   JUNE 20,1977

ATMOSPHERIC DATA TAKEN AT PIER
ELEVATION      2 28M
PSYCHROMETER #1    BAROMETER #1
BAROMETER CORRECTION.  0 05MBAR
OBSERVERS  LAURILA

UNCORRECTED DATA

  TIME       WET     DRY     BAROMETRIC   COMMENTS
HR MN SEC  TEMP     TEMP     PRES(MB)

 2 11  0   20 8     23 3     1017 40*    HELICOPTER TURNING
 0  0  0   20 8     23 3     1017 35
 0  0  0   20 8     23 3     1017 30
 2 15  0   20 7     23 3     1017 30
 0  0  0   20.6     23 3     1017 30
 0  0  0   20 5     23 3     1017.30
 0  0  0   20 5     23 3     1017 35
 2 25  0   20.6     23.3     1017 40
 0  0  0   20 6     23 3     1017 35
 2 27  0   20.6     23 3     1017 35*

REDUCED ATMOSPHERIC DATA

  TIME      DRY    BAROMETRIC     E        N      COMMENTS
HR MN SEC  TEMP    PRES(MB)

 2 11  0   23 1    1017 45     22 94   277.1   HELICOPTER TURNING
 2 12 20   23 1    1017 40     22 94   277 1
 2 13 40   23 1    1017 35     22 94   277 1
 2 15  0   23 1    1017 35     22 72   277 1
 2 17 30   23 1    1017 35     22 50   277 1
 2 20  0   23 1    1017 35     22 28   277 1
 2 22 30   23 1    1017 40     22 28   277 1
 2 25  0   23 1    1017 45     22 50   277 1
 2 26  0   23 1    1017.40     22 50   277 1
 2 27  0   23 1    1017 40     22 50   277 1

MEANS      23 1    1017 39     22 61   277 1
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C-2

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LINE #5 PIER TO ARPA   JUNE 20,1977

REFLECTOR ATMOSPHERIC DATA TAKEN AT ARPA
ELEVATION: 3033.51M
HEIGHT TO THE TOP OF THE TRIBRACH   520 MM
HEIGHT FROM THE TOP OF THE TRIBRACH
  TO THE CENTER OF THE REFLECTORS  287 MM
TOTAL REFLECTOR HEIGHT ABOVE THE MARKER   807.MM
NUMBER OF REFLECTORS: 21
ECCENTRICITY   0MM
PSYCHROMETER #3    BAROMETER #5
BAROMETER CORRECTION:  0.75MBAR
OBSERVERS  WOLFE

UNCORRECTED DATA

  TIME      WET     DRY    BAROMETRIC  COMMENTS
HR MN SEC TEMP    TEMP     PRES(MB)

 2 13   0    0.4     6.8     710.55*   HELICOPTER TURNED AROUND
 2 14   0    0.4     6.8     710.50
 2 15   0    0.5     6.8     710.50
 2 17   0    1.8     6.8     710.45    REWOUND PSYCHROMETER
 2 18   0    0.9     6.8     710.40
 2 19   0    0.8     6.8     710.40
 2 20   0    0.6     6.8     710.45
 2 21   0    0.6     6.8     710.45
 2 22   0    0.7     6.8     710.35
 2 23   0    0.6     6.8     710.40
 2 24   0    0.4     6.7     710.40
 2 25   0    0.5     6.7     710.35
 2 28   0    0.8     6.7     710.15    REWOUND PSY,HEL BREAKING OF
 2 29   0    0.6     6.7     710.25
 2 30   0    0.5     6.7     710.20
 2 31   0    0.6     6.8     710.20*

REDUCED ATMOSPHERIC DATA

  TIME      DRY    BAROMETRIC    E        N      COMMENTS
HR MN SEC TEMP     PRES(MB)

 2 13   0    6.4     711.30     3.59    205.8   HELICOPTER TURNED AROUND
 2 14   0    6.4     711.25     3.60    205.8
 2 15   0    6.4     711.25     3.69    205.8
 2 17   0    6.4     711.20     4.91    205.7   REWOUND PSYCHROMETER
 2 18   0    6.4     711.15     4.06    205.7
 2 19   0    6.4     711.15     3.97    205.7
 2 20   0    6.4     711.20     3.78    205.7
 2 21   0    6.4     711.20     3.78    205.7
 2 22   0    6.4     711.10     3.87    205.7
 2 23   0    6.4     711.15     3.78    205.7
 2 24   0    6.3     711.15     3.61    205.8
 2 25   0    6.3     711.10     3.74    205.8
 2 28   0    6.3     710.90     4.01    205.7   REWOUND PSY,HEL BREAKING OF
 2 29   0    6.3     711.00     3.83    205.8
 2 30   0    6.3     710.95     3.71    205.7
 2 31   0    6.4     710.95     3.78    205.7

MEANS        6.4     711.12     3.86    205.7
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LINE #5 PIER 10 ARPA    JUNE 20,1977

FINAL    CALIBRATION OF THE HELICOPTER HYGRISTOR AT PIER
PSYCHROMETER #4    BAROMETER #2
BAROMETER CORRECTION. -0.25 MBAR
CALIBRATION RESISTANCE OF THE HYGRISTOR   95 0 KOHM
ZERO PRESSURE FREQUENCY OF DIGIQUARTZ  39303 70 HZ
OBSERVER  SCHENCK

UNCORRECTED DATA

  TIME      WET       DRY       THERM     HYGRIS BAROMETRIC  DIGIQTZ   COMMENTS
HR MN SEC TEMP      TEMP      (KOHM)    (KOHM)   PRES(MB)   FREQ (HZ)

 3 28  0  20 2      22.8      16 09      787 0   1015 95     35308 7
 0  0  0  20 2      22 8      16 09      813 0   1015 95     35308 7
 0  0  0  20 2      22 9      16 09      814 0   1015 95     35308 8
 0  0  0  20 2      22 9      16 09      815 0   1015 95     35308 7
 0  0  0  20 2      22 9      16 09      818 0   1015 95     35309 0

REDUCED DATA

  TIME      DIGITAL DIGIQTZ   DRY  THER    E      E
HR MN SEC  PRESS     PRESS    TEMP TEMP   GRND   HELI

 3 28  0   1015 70 1015 84   23 0 23 0   22 01 22 30
 0  0  0   1015 70 1015.84   23 0 23 0   22 01 22 44
 0  0  0   1015 70 1015 81   23 1 23 0   21 94 22 45
 0  0  0   1015 70 1015 84   23 1 23 0   21 94 22 45
 0  0  0   1015 70 1015 76   23 1 23 0   21 94 22 47
```

LINE #5 PIER TO ARPA JUNE 20,1977

HELICOPTER LINE DATA. FLYING FROM ARPA

UNCORRECTED DATA

TIME			ALT	VEL	THERM	DIGIQTZ	HYGRIS	COMMENTS
HR	MN	SEC	(KM)	MPH	KOHM	FREQ (HZ)	KOHM	
2	15	0	2 134	50	19 90	36320 5	18 0*	
0	0	0	0 000	50.	20 00	36300 3	18 0	
0	0	0	0 000	50	19 70	36274 9	19 0	
0	0	0	1 951	50	19 20	36241.6	18 0	
0	0	0	0 000	50	18 90	36205 1	17 0	
0	0	0	1 829	50	18.60	36182 3	17 0	
0	0	0	0.000	50	18 50	36169 6	17 0	
0	0	0	0 000	50	18 40	36162 7	17 0	
2	17	0	2 042	50	18 20	36148 9	16 0	
0	0	0	0 000	50.	18 00	36131 5	17 0	
0	0	0	0 000	50.	18 40	36117 1	24 0	
0	0	0	0 000	50	18 60	36102 7	23 0	
0	0	0	0 000	50	18.60	36079 8	34 0	
0	0	0	0.000	50	19 10	36061 2	37 0	
0	0	0	1 524	50	19 40	36048 5	58 0	
0	0	0	0.000	50.	19 40	36036 2	66 0	
0	0	0	1 463	50	19 70	36023 8	309 0	
0	0	0	0 000	50	20 10	36008 5	481 0	
0	0	0	1 402	50	20 20	35989 2	1325 0	
0	0	0	0 000	50	20 30	35965 1	1262 0	
0	0	0	1 311	50	20 30	35948 5	1359 0	
0	0	0	0 000	50	20 10	35932 5	1303 0	
0	0	0	1 250	50	20 00	35912 1	1368 0	
0	0	0	0 000	50	19 90	35902 9	1586 0	
0	0	0	1 158	50.	19 70	35886 8	1714 0	
0	0	0	0 000	50	19 60	35870.1	1611 0	
0	0	0	1 097	50	19 60	35852 3	1418 0	
0	0	0	0 000	50	19 50	35834 4	1255 0	
0	0	0	0 060	50	19 60	35827 2	1361 0	
2	22	0	1 006	50	19 40	35816 2	1379 0	
0	0	0	0 000	50	19.40	35803 1	1257 0	
0	0	0	0 945	50	19 30	35786 7	1209 0	
0	0	0	0 000	50	19 20	35768 6	0 0	
0	0	0	0 000	50	18 80	35747 9	1489 0	
0	0	0	0 823	50	18 57	35727 1	1589 0	
0	0	0	0 000	50	18 44	35705 9	1598 0	
0	0	0	0 000	50	18 30	35685.9	1616 0	
2	24	0	0 000	0	18 10	35662 1	1599 0	
0	0	0	0 000	0	18 01	35640 9	1568 0	
0	0	0	0 610	0	17 90	35628 7	1547 0	
0	0	0	0 000	0	17 81	35616 0	1182 0	
0	0	0	0 000	0	17 76	35610 3	1423 0	
0	0	0	0 579	0	17 64	35602 4	1326 0	
0	0	0	0 000	0	17 56	35591 6	1227 0	
0	0	0	0 006	0	17 45	35571 7	1141 0	
0	0	0	0 488	0	17 32	35555 8	1051 0	
0	0	0	0 000	0	17 19	35537 5	926 0	
0	0	0	0 000	0	17 13	35524 2	831 0	
0	0	0	0 396	0	16 98	35506 5	688 0	
0	0	0	0 000	0	16 86	35485 2	821 0	
0	0	0	0 274	0	16 83	35464 9	933 0	
0	0	0	0 000	0	16 73	35142 7	905 0	
0	0	0	0 000	0	16 59	35425 7	875 0	

LINE #5 PIER TO ARPA   JUNE 20,1977

UNCORRECTED DATA

TIME			ALT	VEL	THERM.	DIGIQTZ	HYGRIS	COMMENTS
HR	MN	SEC	(KM)	MPH	KOHM	FREQ (HZ)	KOHM	
2	28	0	0 183	50	16 52	35410 7	950 0*	
0	0	0	0 000	0.	16 17	35319 2	873 0	
2	34	0	0 000	0	16 17	35314 5	868 0	
2	35	0	0 000	0.	16 17	35311 7	858 0	

REDUCED HELICOPTER ATMOSPHERIC DATA

TIME			ADJUSTED	PRESS	TEMP	E	N	COMMENTS
HR	MN	SEC	ALT (KM)	(MB)				
2	15	0	2 35830	771 50	14 4	0 00	217 1	
2	15	15	2 30419	776 50	14 2	0 00	218 7	
2	15	30	2 23664	782 77	14 8	0 00	220 0	
2	15	45	2 14873	790.99	15 8	0 00	221 5	
2	16	0	2 05325	799 98	16 5	0 00	223 6	
2	16	15	1 99408	805 60	17 1	0 00	224 6	
2	16	30	1 96126	808 72	17 3	0 00	225 3	
2	16	45	1 94348	810 42	17 5	0 00	225 6	
2	17	0	1 90800	813 81	18 0	0.00	226 2	
2	17	14	1 86343	818 09	18 4	0 00	227 1	
2	17	28	1 82677	821 63	17 5	0 00	228 8	
2	17	42	1 79036	825 17	17 1	0 00	230 1	
2	17	56	1 73286	830 79	17 1	0 00	231 7	
2	18	10	1 68655	835 35	16 1	0 40	233 8	
2	18	24	1 65517	838 46	15 4	2 96	235 0	
2	18	38	1 62490	841.48	15 4	3.65	235 9	
2	18	52	1 59450	844 52	14 8	10 21	237 0	
2	19	6	1 55718	848.26	14 0	11 11	238 6	
2	19	20	1 51041	852 99	13 8	13 42	240 0	
2	19	34	1 45242	858 88	13 6	13 15	241 9	
2	19	48	1 41276	862 94	13 6	13 29	243 0	
2	20	2	1 37469	866 85	14 0	13 56	243 8	
2	20	16	1 32638	871 83	14 2	13 83	245 0	
2	20	30	1 30468	874 08	14 4	14 30	245 5	
2	20	44	1.26680	878 00	14 8	14 82	246 2	
2	20	58	1 22767	882 08	15 0	14 91	247 2	
2	21	12	1 18616	886 41	15 0	14 66	248 4	
2	21	26	1 14464	890 77	15 2	14 60	249 4	
2	21	40	1 12800	892 53	15 0	14 58	250 1	
2	22	0	1 10265	895 20	15 4	15 00	250 5	
2	22	15	1 07254	898 39	15 4	14 80	251 4	
2	22	30	1 03500	902 38	15 6	14 92	252 3	
2	22	45	0 99375	906 78	15 8	15.37	253 4	
2	23	0	0 94676	911 81	16 7	16 46	254 0	
2	23	15	0 89970	916 86	17 2	17 13	254.9	
2	23	30	0 85196	922 00	17 5	17 46	256 1	
2	23	45	0 80715	926 85	17 8	17 84	257 2	
2	24	0	0 75409	932 62	18 2	18 33	258 4	
2	24	15	0 70709	937 75	18 4	18 53	259 6	
2	24	30	0 68014	940 70	18 7	18 79	260 2	
2	24	45	0 65217	943 77	18 9	18 94	260 9	
2	25	0	0 63964	945 15	19 0	18 97	261 1	
2	25	15	0 62230	947 06	19 3	19 13	261 4	
2	25	30	0 59861	949 67	19 4	19 14	262 0	
2	25	45	0.56174	953 75	19 7	19 25	262 9	

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LINE #5 PIER TO ARPA   JUNE 20,1977

REDUCED HELICOPTER ATMOSPHERIC DATA

  TIME     ADJUSTED  PRESS.   TEMP     E       N      COMMENTS
HR MN SEC ALT (KM)    (MB)

 2 26  0  0 52063    958 32   20 0   19 37   263 8
 2 26 15  0 48100    962 73   20 3   19 34   264 8
 2 26 30  0 45231    965 94   20 4   19 14   265 6
 2 26 45  0 41426    970 21   20 8   18 86   266 4
 2 27  0  0 36867    975 34   21 1   19 90   267.5
 2 27 15  0 32543    980 23   21 2   20 67   268 8
 2 27 30  0 27839    985 57   21 4   20 67   270 0
 2 27 45  0.24252    989 66   21.8   21 00   270 8
 2 28  0  0 21099    993 26   21 9   21.55   271 6

MULTIPLICATION CONSTANT TO HUMPHREYS FORMULA= 0 994761
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LINE #5 PIER TO ARPA   JUNE 20,1977

RANGE DATA TAKEN AT PIER
HEIGHT TO THE TOP OF THE TRIBRACH  1125.MM
TOTAL LASER HEIGHT ABOVE THE MARKER. 1365 MM
ECCENTRICITY   0MM
DAYLIGHT FILTER  OUT
A 137 MM OFFSET HAS BEEN DIALED INTO THE INSTRUMENT
LINEARITY CORRECTION.   2 MM
OBSERVERS     LAURILA,HARRIS

UNCORRECTED RANGE DATA

  TIME        RANGE       FREQ    BATTERY THERM        COMMENTS
HR MN SEC   (METERS)      DIFF    VOLTAGE (KOHM)

 2 12  0    30289 366     -2 7    12 310    0 000  TURN AROUND
 0  0  0    30289 363     -2 7    12 310    0 000
 0  0  0    30289 359     -2 7     0 000    0 000
 0  0  0    30289 366      0 0     0 000    0 000
 0  0  0    30289 368      0 0     0 000    0 000
 0  0  0    30289 373      0 0     0 000    0 000
 2 19 30    30289 362      0 0     0 000    0 000
 0  0  0    30289 364      0 0     0 000    0 000
 0  0  0    30289 371      0.0     0 000    0 000
 0  0  0    30289 363      0 0     0.000    0 000
 2 22 10    30289 370      0 0     0.000    0 000
 0  0  0    30289 363      0 0     0 000    0 000
 0  0  0    30289 365      0 0     0 000    0 000
 0  0  0    30289 361      0 0     0 000    0 000
 0  0  0    30289 364      0 0     0 000    0 000
 0  0  0    30289 359      0 0     0 000    0 000
 2 26 30    30289 362      0 0     0 000    0 000
 0  0  0    30289 367      0 0     0 000    0 000
 0  0  0    30289 367      0 0     0 000    0 000
 0  0  0    30289 365      0 0     0 000__  0 000
 0  0  0    30289 369      0 0     0 000    0 000
 0  0  0    30289 365      0 0     0 000    0 000
 0  0  0    30289 372      0 0     0 000    0 000
 0  0  0    30289 362     -3 1    12 290    0 000
 2 29 30    30289 369      0 0     0 000    0.000
 0  0  0    30289 363      0 0     0 000    0.000
 0  0  0    30289 361      0 0     0 000    0 000
 0  0  0    30289 361      0 0     0 000    0 000
 0  0  0    30289 367      0 0     0 000    0 000
 2 33 30    30289 361     -3 2    12 280    0 000

REDUCED RANGE DATA IN METERS

  TIME       FREQUENCY     REDUCED    COMMENTS
HR MN SEC    CORRECTED      RANGE

 2 12  0    30289 384     30291.514   TURN AROUND
 2 13 15    30289 381     30291 511
 2 14 30    30289 377     30291 507
 2 15 45    30289 384     30291 514
 2 17  0    30289 386     30291 516
 2 18 15    30289 391     30291 521
 2 19 30    30289 380     30291 510
 2 20 10    30289 382     30291 512
 2 20 50    30289 389     30291 519
 2 21 30    30289 381     30291 511
```

```
LINE #5 PIER TO ARPA   JUNE 20,1977

REDUCED RANGE DATA IN METERS

  TIME       FREQUENCY      REDUCED     COMMENTS
HR MN SEC   CORRECTED       RANGE

 2 22 10    30289 388     30291 518
 2 22 53    30289.381     30291.511
 2 23 36    30289 384     30291.513
 2 24 19    30289 383     30291 512
 2 25  2    30289 383     30291 512
 2 25 45    30289 378     30291 508
 2 26 30    30289 381     30291 511
 2 26 52    30289 386     30291.516
 2 27 14    30289 386     30291 516
 2 27 36    30289 384     30291 514
 2 27 58    30289 388     30291 518
 2 28 20    30289 384     30291 514
 2 28 42    30289 391     30291 521
 2 29  4    30289 381     30291.511
 2 29 30    30289 388     30291 518
 2 30 18    30289 382     30291 512
 2 31  6    30289 380     30291 510
 2 31 54    30289 380     30291 510
 2 32 42    30289 386     30291 516
 2 33 30    30289 380     30291 510

MEAN LINE LENGTH WITHOUT ATMOSPHERIC CORRECTIONS=  30289 384 METERS
MEAN CORRECTED LINE LENGTH=  30291 514 METERS
STANDARD DEVIATION=  0037 METERS
STANDARD DEVIATION OF THE MEAN=  0007 METERS
MEAN REFRACTIVE NUMBER= 239 24
```

```
LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

ATMOSPHERIC DATA TAKEN AT LUKE
ELEVATION     93 84M
PSYCHROMETER #1    BAROMETER #1
BAROMETER CORRECTION:  0 00MBAR
OBSERVERS  SUTTON

UNCORRECTED DATA

  TIME      WET      DRY    BAROMETRIC   COMMENTS
HR MN SEC TEMP     TEMP     PRES(MB)

 4 52  0  20.2     22 6     1007 60     REWOUND PSYCHROMETER
 4 54  0  20 2     22 6     1007 60
 4 55  0  20.2     22 7     1007 65
 4 57  0  20 2     22 6     1007 65
 4 58  0  20 2     22 5     1007 65*    HELICOPTER CALIBRATION
 5  1  0  20 2     22 4     1007 65     REWOUND PSYCHROMETER
 5  3  0  20 0     22 4     1007 65
 5  4  0  20 0     22 3     1007 65
 5  6  0  20 0     22 3     1007 65
 5  8  0  20 0     22 2     1007 70
 5 10  0  20.1     22 2     1007 65     REWOUND PSYCHROMETER
 5 12  0  20 0     22 1     1007 70
 5 14  0  20 2     22 2     1007 70
 5 16  0  20 2     22 2     1007 75
 5 18  0  20 2     22 2     1007 80
 5 20  0  20.2     22 2     1007 80     REWOUND PSYCHROMETER
 5 22  0  20 2     22 2     1007 80
 5 24  0  20 2     22 2     1007 80
 5 26  0  20.2     22 3     1007 80
 5 28  0  20.3     22 3     1007 80*

REDUCED ATMOSPHERIC DATA

  TIME     DRY    BAROMETRIC    E        N      COMMENTS
HR MN SEC TEMP     PRES(MB)

 4 58  0  22 3     1007 65     22 20    275 2   HELICOPTER CALIBRATION
 5  1  0  22 2     1007 65     22 27    275 3   REWOUND PSYCHROMETER
 5  3  0  22 2     1007 65     21 84    275 3
 5  4  0  22.1     1007 65     21 91    275 4
 5  6  0  22 1     1007 65     21 91    275 4
 5  8  0  22 0     1007 70     21 97    275 5
 5 10  0  22 0     1007 65     22 19    275 5   REWOUND PSYCHROMETER
 5 12  0  21 9     1007 70     22 04    275 6
 5 14  0  22 0     1007.70     22 40    275 5
 5 16  0  22 0     1007 75     22 40    275 5
 5 18  0  22 0     1007 80     22 40    275 5
 5 20  0  22 0     1007 80     22 40    275 5   REWOUND PSYCHROMETER
 5 22  0  22 0     1007 80     22 40    275.5
 5 24  0  22 0     1007.80     22 40    275 5
 5 26  0  22 1     1007 80     22 33    275 4
 5 28  0  22 1     1007 80     22 55    275 4

MEANS     22 1     1007 72     22 23    275 4
```

LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

REFLECTOR ATMOSPHERIC DATA TAKEN AT PUU NIANIAU
ELEVATION . 2087.90M
HEIGHT TO THE TOP OF THE TRIBRACH   787.MM
HEIGHT FROM THE TOP OF THE TRIBRACH
  TO THE CENTER OF THE REFLECTORS 236 MM
TOTAL REFLECTOR HEIGHT ABOVE THE MARKER 1023 MM
NUMBER OF REFLECTORS 18
ECCENTRICITY   0MM
PSYCHROMETER #2   BAROMETER #6
BAROMETER CORRECTION. 0.25MBAR
OBSERVERS CUSHMAN

UNCORRECTED DATA

TIME			WET	DRY	BAROMETRIC	COMMENTS
HR	MN	SEC	TEMP	TEMP	PRES(MB)	
4	56	0	5 3	13 8	798 25	
4	57	0	5 4	13 0	798 17	
4	58	0	5 3	13 1	798 18	
4	59	0	5 3	13 1	798 25	
5	0	0	0.0	13 0	798 28	
5	1	0	5.6	13 0	798 24	REWOUND PSYCHROMETER
5	2	0	5 4	13 0	798 25	
5	3	0	5 4	13 2	798 26	
5	4	0	5 4	13 1	798 12	
5	5	0	5 4	13 1	798 29	
5	6	0	5 6	13 0	798 37	REWOUND PSYCHROMETER
5	7	0	5.4	12 9	798 28	
5	8	0	5 9	13 2	798 40	
5	9	0	5 4	13 1	798 36	
5	10	0	5 4	13 2	798 44	
5	11	0	0 0	13.2	798 50	REWOUND PSYCHROMETER
5	12	0	5 4	13 2	798 47	
5	13	0	5 4	13 2	798 40	
5	14	0	5 4	13 2	798 17	
5	15	0	5 3	13 0	798 52	
5	16	0	0 0	13 1	798 52	REWOUND PSYCHROMETER
5	17	0	5 5	13 0	798 50	
5	18	0	5 1	13 0	798 45	
5	19	0	5 4	13 1	798 48	
5	20	0	5 4	13 0	798 53	
5	21	0	0 0	13 0	798.54	REWOUND PSYCHROMETER
5	22	0	5 6	13 2	798.56	
5	23	0	5 5	13 1	798 57	
5	24	0	5 3	12 9	798 57	
5	25	0	5 2	12 7	798 56	
5	26	0	0 0	13 0	798 50	REWOUND PSYCHROMETER
5	27	0	5 6	13 0	798 51	
5	28	0	5 5	13 2	798 51	

LINE #6 LUKE TO PUU NIANIAU JUNE 21, 1977

REDUCED ATMOSPHERIC DATA

TIME HR	TIME MN	TIME SEC	DRY TEMP	BAROMETRIC PRES(MB)	E	N	COMMENTS
4	57	0	12.9	798.42	4.97	225.7	
4	58	0	13.0	798.43	4.80	225.6	
4	59	0	13.0	798.50	4.80	225.6	
5	0	0	12.9	798.53	5.03	225.7	
5	1	0	12.9	798.49	5.20	225.7	REWOUND PSYCHROMETER
5	2	0	12.9	798.50	4.97	225.7	
5	3	0	13.1	798.51	4.87	225.6	
5	4	0	13.0	798.37	4.92	225.6	
5	5	0	13.0	798.54	4.92	225.7	
5	6	0	12.9	798.62	5.20	225.7	REWOUND PSYCHROMETER
5	7	0	12.8	798.53	5.03	225.8	
5	8	0	13.1	798.65	5.45	225.6	
5	9	0	13.0	798.61	4.92	225.7	
5	10	0	13.1	798.69	4.86	225.6	
5	11	0	13.1	798.75	4.86	225.6	REWOUND PSYCHROMETER
5	12	0	13.1	798.72	4.86	225.6	
5	13	0	13.1	798.65	4.86	225.6	
5	14	0	13.1	798.72	4.86	225.6	
5	15	0	12.9	798.77	4.86	225.8	
5	16	0	13.0	798.77	4.92	225.7	REWOUND PSYCHROMETER
5	17	0	12.9	798.75	5.09	225.8	
5	18	0	12.9	798.70	4.97	225.8	
5	19	0	13.0	798.73	4.92	225.7	
5	20	0	12.9	798.78	4.97	225.8	
5	21	0	12.9	798.79	5.09	225.8	REWOUND PSYCHROMETER
5	22	0	13.1	798.81	5.10	225.6	
5	23	0	13.0	798.82	5.03	225.7	
5	24	0	12.8	798.82	4.91	225.9	
5	25	0	12.6	798.81	4.90	226.0	
5	26	0	12.9	798.75	4.97	225.8	REWOUND PSYCHROMETER
5	27	0	12.9	798.76	5.20	225.8	
5	28	0	13.1	798.76	4.98	225.6	
MEANS			13.0	798.66	4.98	225.7	

```
LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

INITIAL  CALIBRATION OF THE HELICOPTER HYGRISTOR AT AIRPORT
PSYCHROMETER #2     BAROMETER #2
BAROMETER CORRECTION  -0.25 MBAR
CALIBRATION RESISTANCE OF THE HYGRISTOR   76.0 KOHM
ZERO PRESSURE FREQUENCY OF DIGIQUARTZ  39298.81 HZ
OBSERVER- HARRIS

UNCORRECTED DATA

  TIME      WET      DRY       THERM     HYGRIS  BAROMETRIC  DIGIQTZ   COMMENTS
HR MN SEC TEMP     TEMP      (KOHM)    (KOHM)   PRES(MB)   FREQ.(HZ)

 4 35   0   19.8     22.2      16.14      952.0   1016.60     35299.8   COLD
 4 37   0    0.0      0.0      16.40      970.0   1016.60     35300.1   COLD
 4 40   0   19.4     21.8      16.69      936.0   1016.63     35299.8   COLD

REDUCED DATA

  TIME      DIGITAL  DIGIQTZ   DRY   THER     E      E
HR MN SEC   PRESS     PRESS    TEMP  TEMP   GRND   HELI

 4 35   0   1016.35  1016.91   22.2  22.1   21.72  22.62
 4 37   0   1016.35  1016.84   22.0  22.2   21.44  22.83
 4 40   0   1016.38  1016.91   21.8  21.5   21.15  21.70
```

LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977

HELICOPTER LINE DATA. FLYING FROM LUKE

UNCORRECTED DATA

TIME			ALT	VEL	THERM	DIGIQTZ	HYGRIS	COMMENTS
HR	MN	SEC	(KM)	MPH	KOHM	FREQ (HZ)	KOHM	
4	45	0	0 000	0.	16 48	35299 4	968 0	STARTING ENGINES
4	48	0	0 000	0.	16 39	35247 1	981 0	
4	52	50	0 213	50.	16 73	35412 6	1015 0	
4	53	2	0 213	0	16.58	35406.9	978 0	
0	0	0	0 207	0.	16.52	35400 9	974 0	
0	0	0	0 000	1	0 00	35340 1	0 0*	LEVELING AT LUKE
0	0	0	0 000	0.	0 00	35337 4	0 0	
0	0	0	0 000	0.	0 00	35338 2	0 0	
0	0	0	0 000	1.	0 00	35337 5	0 0	
4	56	0	0 000	50.	16 30	35337 8	1047 0	STARTING LINE
0	0	0	0 000	0.	16 46	35365 9	1007.0	
0	0	0	0 000	0	16 46	35378 5	1013 0	
0	0	0	0 000	0.	16 46	35380 2	972 0	
0	0	0	0 000	0	16 60	35392 0	991 0	
0	0	0	0 000	0	16.63	35406 1	0 0	
0	0	0	0 000	0	16 82	35419 7	832 0	
0	0	0	0 000	0	16 95	35429 6	874 0	
4	58	0	0 000	0	17 05	35439 4	851.0	
0	0	0	0 000	0.	17 17	35452 0	827 0	
0	0	0	0 000	0.	17 25	35462.7	755 0	
0	0	0	0 000	0.	17 35	35466 3	695 0	
0	0	0	0 000	0	17 38	35474 5	733.0	
0	0	0	0 000	0	17 30	35484 2	1057 0	
5	0	0	0 000	0	17 17	35491 2	1103 0	
0	0	0	0 000	0	17 27	35500 7	1007 0	
0	0	0	0 000	0	17 43	35511 5	1114 0	
0	0	0	0 000	0	17 35	35523 8	1174 0	
0	0	0	0 457	50	17 53	35529 7	1150 0	
5	1	0	0 518	0	17 62	35565 9	1190 0	
0	0	0	0 000	0	17 72	35586 9	1176 0	
0	0	0	0 000	0	17 81	35597 5	1163 0	
0	0	0	0 000	0	17 85	35605 3	1153 0	
5	3	0	0 000	0	17 98	35610 7	1158 0	
0	0	0	0 000	0	18 01	35620 3	1188 0	
0	0	0	0 000	0	18 04	35632 1	1177 0	
0	0	0	0 000	0	18 18	35649 1	1129 0	
0	0	0	0 000	0	18 25	35659 2	1069 0	
5	4	0	0 732	50	18 38	35671 3	1039 0	
0	0	0	0 000	0	18 44	35675 6	1025 0	
0	0	0	0 000	0	18 57	35689 4	946 0	
0	0	0	0 000	0	18 66	35704 6	917 0	
0	0	0	0 000	0	18 71	35715 3	913 0	
0	0	0	0 000	0	18 81	35728 1	900 0	
0	0	0	0 000	0.	18 89	35736 7	850 0	
0	0	0	0 000	0	18 93	35743 6	862 0	
5	6	0	0 000	0	18 99	35752 4	863 0	
0	0	0	0 000	0	19 09	35762 1	814 0	
0	0	0	0 000	0	19 21	35774 7	779 0	
0	0	0	0.000	0	19 29	35785 3	750 0	
5	7	0	0 000	0	19 30	35795 4	853 0	
0	0	0	0 000	0.	19 28	35802 0	1044 0	
0	0	0	0 000	0	19 22	35809 3	1174 0	
0	0	0	0.000	0	19 19	35820 0	1234 0	

LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

UNCORRECTED DATA

```
  TIME       ALT.   VEL   THERM     DIGIQTZ   HYGRIS   COMMENTS
HR MN SEC    (KM)   MPH    KOHM    FREQ (HZ)   KOHM

0   0   0   0 000    0.    19 21    35831 8   1239 0
0   0   0   0 000    0     18 87    35841 5    370 0
5   8   0   1 128    0.    18 02    35861 4     50 0
0   0   0   0 000    0.    17 39    35868 0     36 0
0   0   0   0 000    0.    17 86    35871 1     43 0
5   9   0   0 000    0     17 95    35875 0     40 0
5  10   0   1 219   50     17 61    35891 2     30 0
0   0   0   0 000    0     17 76    35905 9     31,0
0   0   0   0 000    0.    17 83    35908 4     35 0
0   0   0   0 000    0     18 02    35908 9     22 0
0   0   0   0 000    0     17 26    35924 0     22 0
0   0   0   0.000    0     17 42    35930 1     21 0
0   0   0   0 000    0     17 42    35935 5     20 0
5  11   0   1 311   50     16 89    35946 9     18 0
0   0   0   0 000    0     16 93    35955 3     17 0
0   0   0   0 000    0     17 59    35953 4     19 0
0   0   0   0.000    0     17 69    35950 0     29 0
0   0   0   0 000    0     17 60    35953 9     18 0
0   0   0   1 372   55     17 12    35971 9     17 0
0   0   0   0 000    0     17 19    35934 2     18 0
0   0   0   0 000    0     17 59    35991 2     18 0
5  13   0   0 000    0     17 44    35998 4     18 0
0   0   0   0 000    0     17 48    36009 4     18 0
0   0   0   0 000    0     17 45    36018 7     18 0
0   0   0   0 000    0     17 55    36017 6     17 9
5  14   0   0 000    0     17 58    36015 8     17 9
0   0   0   0 000    0     17 68    36022 4     18 1
0   0   0   0 000    0     17 71    36027 6     18 2
0   0   0   0 000    0     17 76    36033 8     18 1
0   0   0   1 521   50     17 82   -36039 6      0 0
0   0   0   0 000    0     17 87    36015 2     13 1
0   0   0   0 000    0     17 70    36051 3     17 8
0   0   0   0 000    0     17 67    36051 6     17 7
5  16   0   0 000    0     17 67    36052 5     17 6
0   0   0   0 000    0     17 61    36054 7     17 8
5  17   0   0 000    0     17 63    36060 7     18 4
0   0   0   1 585    0     17 64    36063 7     18 7
0   0   0   0 000    0     17 63    36069 3     19 1
0   0   0   0 000    0     17 56    36073 3     18 5
5  18   0   0 000    0     17 57    36077 6     18 5
0   0   0   0 000    0     17 61    36082 0     18 5
0   0   0   0 000    0.    17 69    36086 7     18 6
5  19   0   0 000    0     17 79    36091 8     18 9
0   0   0   1 676   45     17 90    36106 1     18 8
0   0   0   0 000    0     17 95    36115 9     18 9
0   0   0   0 000    0     18 01    36121 0     19 0
5  20   0   0 000    0     18 14    36123 9     20 0
0   0   0   0 000    0     18 22    36126 8     20 5
0   0   0   0 000    0     18 30    36130 1     19 7
0   0   0   0 000    0     18 41    36135 9     19 7
0   0   0   0 000    0     18 49    36137 8     19 2
5  21   0   0 000    0     18 63    36143 3     19 2
0   0   0   0 000    0     18 72    36154 1     19 5
0   0   0   0 000    0     18 77    36160 3     18 8
0   0   0   0 000    0     18 88    36159 9     19 0
0   0   0   0 000    0     18 91    36162 1     19 3
```

LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977

UNCORRECTED DATA

TIME			ALT	VEL	THERM.	DIGIQTZ	HYGRIS	COMMENTS
HR	MN	SEC	(KM)	MPH	KOHM	FREQ (HZ)	KOHM	
5	22	0	1 829	45.	19 24	36166 5	19 9	
0	0	0	0 000	0	19.20	36169 4	19 9	
0	0	0	0 000	0	19.21	36178 3	20.3	
0	0	0	0 000	0	0 00	36186.3	0.0	LEVELING
0	0	0	0 000	0	19 51	36193 1	0.0	
5	24	0	2 038	45	19 51	36195 9	20 3*	

REDUCED HELICOPTER ATMOSPHERIC DATA

TIME			ADJUSTED	PRESS	TEMP	E	N	COMMENTS
HR	MN	SEC	ALT (KM)	(MB)				
4	54	0	0 09780	1007 26	22 1	22 62	275 3	LEVELING AT LUKE
4	54	29	0 09221	1007 91	22.2	22 82	275 4	
4	54	58	0 09387	1007 72	22 3	23 03	275 2	
4	55	27	0 09242	1007 89	22 4	23 23	275 1	
4	56	0	0 07671	1009 70	22 5	23 44	275 5	STARTING LINE
4	56	15	0 13513	1002 96	22 1	22 73	274 1	
4	56	30	0 16145	999 94	22 1	22 75	273 3	
4	56	45	0 16501	999 53	22 1	22 62	273 1	
4	57	0	0 18974	996 70	21 7	22 19	272 7	
4	57	15	0 21936	993 31	21 7	21.81	271 9	
4	57	30	0 24801	990 01	21 2	20.87	271 4	
4	57	45	0 26890	987 66	20 9	20 62	271 1	
4	58	0	0 28962	985 30	20 6	20 22	270 7	
4	58	20	0 31630	982 27	20 4	19 76	270 1	
4	58	40	0 33902	979 69	20 2	19 23	269 6	
4	59	0	0.34667	978 83	19 9	18 66	269 6	
4	59	20	0 36411	976 85	19 9	18 76	269 1	
4	59	40	0 38481	974 52	20.0	20 11	268 2	
5	0	0	0 39980	972.83	20 4	20 63	267 5	
5	0	12	0.42019	970 54	20 1	20 06	267.1	
5	0	24	0 44341	967 94	19 7	19 87	266 7	
5	0	36	0 46994	964 97	19 9	20 24	265 7	
5	0	48	0 48269	963 55	19 5	19 65	265 7	
5	1	0	0 56130	954 81	19 3	19 48	263 5	
5	1	30	0 60723	949 71	19 1	19 17	262 3	
5	2	0	0 63051	947 18	18 9	18 89	261 8	
5	2	30	0 64767	915 29	18 8	18 76	261 4	
5	3	0	0.65957	943 98	18 5	18 42	261 3	
5	3	12	0 68074	941 66	18 4	18 40	260 7	
5	3	24	0 70685	938 81	18 3	18 30	260 0	
5	3	36	0 74459	934 69	18 0	17 83	259 1	
5	3	48	0 76708	932 21	17 9	17 52	258 6	
5	4	0	0 79408	929 31	17 6	17 11	258 0	
5	4	15	0 80370	928 27	17 5	16 95	257 9	
5	4	30	0 83460	924 93	17 2	16 45	257 2	
5	4	45	0 86876	921 21	17 0	16 16	256 4	
5	5	0	0 89288	918 64	16 9	16 04	255 7	
5	5	15	0 92181	915 54	16 7	15 78	255 1	
5	5	30	0 94130	913 45	16 5	15 46	254 7	
5	5	45	0 95697	911 77	16 4	15 41	254 3	
5	6	0	0 97699	909 64	16 3	15 29	253 8	
5	6	15	0.99910	907 28	16 1	14 93	253 3	
5	6	30	1 02789	904 22	15 8	14 58	252 7	

```
LINE *6 LUKE TO PUU NIANIAU   JUNE 21,1977

REDUCED HELICOPTER ATMOSPHERIC DATA

  TIME     ADJUSTED  PRESS    TEMP     E       N     COMMENTS
HR MN SEC ALT (KM)    (MB)

 5 20 48  1 91524   815 11   17 3    0 00   227 1
 5 21  0  1 93193   813 51   17 0    0 00   226 9
 5 21 12  1 95790   811 03   16 9    0 00   226 4
 5 21 24  1 97310   809 58   16 7    0 00   226 0
 5 21 36  1 97207   809 68   16 5    0 00   226 2
 5 21 48  1 97774   809 14   16 4    0 00   226 2
 5 22  0  1 98908   808 05   15 8    0 00   226 4
 5 22 24  1 99655   807 31   15 8    0 00   226 1
 5 22 48  2 01954   805 15   15 8    0 00   225 5
 5 23 12  2 01025   803 18   15 5    0.00   225 2  LEVELING
 5 23 36  2 05788   801 51   15 2    0 00   225 0
 5 24  0  2 06514   800 82   15 2    0 00   224 8

MULTIPLICATION CONSTANT TO HUMPHREYS FORMULA= 0.998215
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LINE #6 LUKE TO PUU NIANIAU JUNE 21, 1977

REDUCED HELICOPTER ATMOSPHERIC DATA

TIME			ADJUSTED	PRESS	TEMP	E	N	COMMENTS
HR	MN	SEC	ALT (KM)	(MB)				
5	6	45	1 05218	901 64	15 7	14 33	252 1	
5	7	0	1 07539	899 18	15 6	14.62	251 4	
5	7	10	1 09059	897 58	15 7	15 13	250 9	
5	7	20	1 10745	895 80	15 8	15 50	250 3	
5	7	30	1.13225	893 19	15 9	15 67	249 5	
5	7	40	1 15969	890 32	15 8	15 63	248 8	
5	7	50	1 18234	887 96	16 5	12 97	247 6	
5	8	0	1 22910	883 11	18 4	4 01	245 0	
5	8	20	1 24472	881 50	19 8	1 88	243 4	
5	8	40	1 25208	880 74	18 7	3 05	244 1	
5	9	0	1 26132	879 79	18 5	2 52	244 0	
5	10	0	1.29984	875 84	19 3	0 44	242 4	
5	10	8	1 33497	872 25	19 0	0 69	241.6	
5	10	16	1 34096	871.64	18 8	1 59	241.6	
5	10	24	1 34216	871 52	18 4	0 00	242 0	
5	10	32	1 37846	867 83	20 1	0 00	239 5	
5	10	40	1 39321	866 34	19 8	0 00	239.4	
5	10	48	1 40628	865 02	19 8	0 00	239 0	
5	11	0	1 43400	862 24	21 0	0 00	237 2	
5	11	15	1 45380	860.26	20 9	0 00	236 8	
5	11	30	1 44811	860 80	19 4	0 00	238 2	
5	11	45	1 43939	861 71	19 1	0 00	238 6	
5	12	0	1 44809	860.83	19 3	0 00	238 2	
5	12	15	1 49129	856 51	20 5	0 00	236 1	
5	12	30	1 52192	853 46	20 3	0 00	235 4	
5	12	45	1 53953	851 71	19 4	0 00	235 7	
5	13	0	1 55764	849 91	19 7	0.00	234 9	
5	13	15	1.58522	847 18	19 6	0 00	234 2	
5	13	30	1 60866	844 87	19 7	0.00	233 5	
5	13	45	1 60628	845 10	19.5	0 00	233.8	
5	14	0	1 60215	845 51	19.4	0 00	233 9	
5	14	15	1.61889	843 86	19 2	0 00	233 7	
5	14	30	1 63216	842.55	19 1	0 00	233 4	
5	14	45	1 64793	841 00	19 0	0 00	233 0	
5	15	0	1 66273	839 55	18 8	0 00	232 7	
5	15	15	1 67698	838 15	18 7	0 00	232 4	
5	15	30	1 69877	836 51	19 1	0 00	231 7	
5	15	45	1 69852	836 53	19 2	0 00	231 6	
5	16	0	1 69603	836 28	19 2	0 00	231 5	
5	16	30	1 70180	835 72	19 3	0 00	231 3	
5	17	0	1 71714	834 23	19 3	0 00	230 9	
5	17	15	1 72494	833 47	19 3	0 00	230 7	
5	17	30	1 73981	832 07	19 3	0 00	230 3	
5	17	45	1 74965	831 06	19 4	0.00	229 9	
5	18	0	1 76078	829 99	19 4	0 00	229 6	
5	18	20	1 77216	828 88	19 3	0 00	229 4	
5	18	40	1 78132	827 71	19 1	0 00	229 2	
5	19	0	1 80513	825.70	18 9	0 00	228 8	
5	19	15	1 83113	822 90	18 7	0 00	228 2	
5	19	30	1.85915	820 49	18 5	0 00	227 7	
5	19	45	1 87220	819 24	18 3	0 00	227 5	
5	20	0	1 87962	818 53	18 1	0 00	227 5	
5	20	12	1 88705	817 82	17 9	0 00	227 4	
5	20	21	1 89550	817 00	17 8	0 00	227 3	
5	20	36	1 91037	815 58	17 5	0 00	227 1	

```
LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

RANGE DATA TAKEN AT LUKE
HEIGHT TO THE TOP OF THE TRIBRACH. 1017.MM
TOTAL LASER HEIGHT ABOVE THE MARKER  1257 MM
ECCENTRICITY.  0MM
DAYLIGHT FILTER  OUT
A 137 MM OFFSET HAS BEEN DIALED INTO THE INSTRUMENT
LINEARITY CORRECTION.    7 MM
OBSERVERS  CARTER,SUTTON,WOLFE

UNCORRECTED RANGE DATA

  TIME        RANGE       FREQ    BATTERY THERM        COMMENTS
HR MN SEC   (METERS)     DIFF    VOLTAGE (KOHM)

 4 47  0    28841 245     2 0    12 590   0 000
 0  0  0    28841 243     0 0    0.000    0 000
 0  0  0    28841 237     0 0     0 000   0 000k
 0  0  0    28841 235     0.0     0 000   0 000
 0  0  0    28841 245     1 0    12.590   0 000
 5  0  0    28841 244     0 0     0 000   0 000
 0  0  0    28841 239     0 0     0 000   0 000
 0  0  0    28841 236     0 0    12 580   0 000
 5  3  0    28841 238     0 0     0 000   0 000
 0  0  0    28841 239     0 0     0 000   0 000
 0  0  0    28841 238     0 0     0 000   0 000
 0  0  0    28841 239     0 0     0 000   0 000
 0  0  0    28841 238     0 0     0 000   0 000
 5  5  0    28841 236     0 0    12 530   0 000
 0  0  0    28841 237     0 0     0 000   0 000
 0  0  0    28841 237     0 0     0 000   0 000
 0  0  0    28841 240     0 0     0 000   0 000
 0  0  0    28841 231     0 0     0 000   0 000
 0  0  0    28841 238     0 0     0 000   0 000
 5  9  0    28841 244    -1 0    12 560   0 000
 0  0  0    28841 238     0 0     0 000   0 000
 0  0  0    28841 239     0 0     0 000   0 000
 0  0  0    28841 238     0 0     0 000   0 000
 0  0  0    28841 238     0 0     0 000   0 000
 0  0  0    28841 233     0 0     0 000   0 000
 0  0  0    28841 238     0 0     0 000   0 000
 5 16  0    28841 238    -2 0    12 550   0 000
 0  0  0    28841 239     0 0     0 000   0 000
 0  0  0    28841 234     0 0     0 000   0 000
 0  0  0    28841 231     0 0     0 000   0 000
 0  0  0    28841 234     0.0     0 000   0 000
 5 18  0    28841 234    -3 0    12 550   0 000
 0  0  0    28841 235     0 0     0 000   0 000
 0  0  0    28841 235     0 0     0 000   0 000
 0  0  0    28841 240     0 0     0 000   0 000
 0  0  0    28841 238     0 0     0 000   0 000
 0  0  0    28841 235     0 0     0 000   0 000
 0  0  0    28841 235     0 0     0 000   0 000
 0  0  0    28841 262     0 0     0 000   0 000
 0  0  0    28841 233     0 0     0 000   0 000
 0  0  0    28841 242     0 0     0 000   0 000
 0  0  0    28841 231     0 0     0 000   0.000
 0  0  0    28841 231     0 0     0 000   0 000
 0  0  0    28841 230     0 0     0 000   0 000
 5 22  0    28841 235    -4 0    12 540   0 000k
```

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LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

REDUCED RANGE DATA IN METERS

  TIME      FREQUENCY      REDUCED     COMMENTS
HR MN SEC   CORRECTED       RANGE

 4 52 12   28841 212     28842 956
 4 54 48   28841 211     28842 955
 4 57 24   28841 221     28842 965
 5  0  0   28841 221     28842 965
 5  1  0   28841 216     28842 960
 5  2  0   28841 214     28842 958
 5  3  0   28841 216     28842 960
 5  3 24   28841 217     28842 961
 5  3 48   28841.216     28842 960
 5  4 12   28841.217     28842 961
 5  4 36   28841 216     28842 960
 5  5  0   28841 214     28842 958
 5  5 40   28841 215     28842 960
 5  6 20   28841 216     28842 960
 5  7  0   28841 219     28842 963
 5  7 40   28841 210     28842.954
 5  8 20   28841 218     28842 962
 5  9  0   28841 224     28842 968
 5 10  0   28841 218     28842 962
 5 11  0   28841 219     28842 964
 5 12  0   28841 219     28842 963
 5 13  0   28841.219     28842 963
 5 14  0   28841 214     28842 958
 5 15  0   28841 220     28842 964
 5 16  0   28841 220     28842 964
 5 16 24   28841 221     28842 965
 5 16 48   28841 217     28842 961
 5 17 12   28841 214     28842 958
 5 17 36   28841 217     28842 962
 5 18  0   28841 218     28842 962
 5 18 18   28841 219     28842 963
 5 18 36   28841 219     28842 963
 5 18 54   28841 224     28842 968
 5 19 12   28841 222     28842 967
 5 19 30   28841 220     28842 964
 5 19 48   28841 220     28842 964
 5 20  6   28841 217     28842 961
 5 20 24   28841 218     28842 962
 5 20 42   28841 227     28842 971
 5 21  0   28841 216     28842.960
 5 21 18   28841 216     28842 961
 5 21 36   28841 216     28842 960
 5 22  0   28841.221     28842 965

MEAN LINE LENGTH WITHOUT ATMOSPHERIC CORRECTIONS=  28841 218 METERS
MEAN CORRECTED LINE LENGTH=  28842 962 METERS
STANDARD DEVIATION=  0034 METERS
STANDARD DEVIATION OF THE MEAN= .0005 METERS
MEAN REFRACTIVE NUMBER= 249 10
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LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

ATMOSPHERIC DATA TAKEN AT LUKE
ELEVATION     93.81M
PSYCHROMETER #1    BAROMETER #1
BAROMETER CORRECTION    0.00MBAR
OBSERVERS   SUTTON

UNCORRECTED DATA

  TIME      WET      DRY    BAROMETRIC   COMMENTS
HR MN SEC TEMP     TEMP     PRES(MB)

 5 30   0  20.3     22.3     1007.80*
 5 32   0  20.3     22.2     1007.85     REWOUND PSYCHROMETER
 5 34   0  20.4     22.2     1007.85
 5 36   0  20.3     22.2     1007.90
 5 38   0  20.2     22.1     1007.90
 5 40   0  20.4     22.0     1007.95
 5 42   0  20.4     21.8     1007.95     REWOUND PSYCHROMETER
 5 44   0  20.4     21.8     1008.00
 5 48   0  20.4     21.8     1008.00*

REDUCED ATMOSPHERIC DATA

  TIME      DRY   BAROMETRIC     E        N      COMMENTS
HR MN SEC TEMP     PRES(MB)

 5 30   0  22.1    1007.80    22.55   275.4
 5 32   0  22.0    1007.85    22.62   275.5   REWOUND PSYCHROMETER
 5 34   0  22.0    1007.85    22.83   275.5
 5 36   0  22.0    1007.90    22.62   275.5
 5 38   0  21.9    1007.90    22.47   275.6
 5 40   0  21.8    1007.95    22.97   275.7
 5 42   0  21.6    1007.95    23.10   275.9   REWOUND PSYCHROMETER
 5 44   0  21.6    1008.00    23.10   275.9
 5 48   0  21.6    1008.00    23.10   275.9

MEANS      21.9    1007.91    22.82   275.6
```

LINE #6 LUKE TO PUU NIANIAU JUNE 21, 1977

REFLECTOR ATMOSPHERIC DATA TAKEN AT PUU NIANIAU
ELEVATION . 2087.90M
HEIGHT TO THE TOP OF THE TRIBRACH 787 MM
HEIGHT FROM THE TOP OF THE TRIBRACH
TO THE CENTER OF THE REFLECTORS 236 MM
TOTAL REFLECTOR HEIGHT ABOVE THE MARKER 1023 MM
NUMBER OF REFLECTORS 18
ECCENTRICITY 0MM
PSYCHROMETER #2 BAROMETER #6
BAROMETER CORRECTION 0.25MBAR
OBSERVERS CUSHMAN

UNCORRECTED DATA

TIME HR	 MN	 SEC	WET TEMP	DRY TEMP	BAROMETRIC PRES(MB)	COMMENTS
5	29	0	5.4	13.0	798.54	HELICOPTER
5	30	0	5.5	13.1	798.56	
5	31	0	0.0	13.2	798.56	REWOUND PSYCHROMETER
5	32	0	5.6	13.1	798.54	
5	33	0	5.5	13.2	798.55	
5	34	0	5.5	13.3	798.56	
5	35	0	5.5	13.2	798.51	
5	36	0	0.0	13.3	798.60	REWOUND PSYCHROMETER
5	37	0	5.5	13.0	798.57	
5	38	0	5.5	13.2	798.67	
5	39	0	5.5	13.1	798.77	
5	40	0	5.5	13.0	798.79	
5	41	0	0.0	12.9	798.76	REWOUND PSYCHROMETER
5	42	0	5.5	13.1	798.74	
5	43	0	5.9	12.9	798.75	
5	44	0	5.9	13.1	798.75	
5	45	0	5.4	13.1	798.76	REWOUND PSYCHROMETER

REDUCED ATMOSPHERIC DATA

TIME HR	 MN	 SEC	DRY TEMP	BAROMETRIC PRES(MB)	E	N	COMMENTS
5	29	0	12.9	798.79	4.97	225.8	HELICOPTER
5	30	0	13.0	798.81	5.03	225.7	
5	31	0	13.1	798.81	5.04	225.6	REWOUND PSYCHROMETER
5	32	0	13.0	798.79	5.15	225.7	
5	33	0	13.1	798.80	4.98	225.6	
5	34	0	13.2	798.81	4.93	225.6	
5	35	0	13.1	798.76	4.98	225.6	
5	36	0	13.2	798.85	4.93	225.6	REWOUND PSYCHROMETER
5	37	0	12.9	798.82	5.09	225.8	
5	38	0	13.1	798.92	4.98	225.7	
5	39	0	13.0	799.02	5.03	225.8	
5	40	0	12.9	799.04	5.09	225.9	
5	41	0	12.8	799.01	5.14	225.9	REWOUND PSYCHROMETER
5	42	0	13.0	798.99	5.03	225.8	
5	43	0	12.8	799.00	5.61	225.9	
5	44	0	13.0	799.00	5.50	225.8	
5	45	0	13.0	799.01	4.92	225.8	REWOUND PSYCHROMETER
MEANS			13.0	798.90	5.08	225.7	

```
LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

FINAL     CALIBRATION OF THE HELICOPTER HYGRISTOR AT AIRPORT
PSYCHROMETER #2     BAROMETER #2
BAROMETER CORRECTION  -0 23 MBAR
CALIBRATION RESISTANCE OF THE HYGRISTOR   76 0 KOHM
ZERO PRESSURE FREQUENCY OF DIGIQUARTZ  39298 81 HZ
OBSERVER  HARRIS

UNCORRECTED DATA

  TIME      WET      DRY      THERM     HYGRIS BAROMETRIC  DIGIQTZ  COMMENTS
HR MN SEC TEMP     TEMP     (KOHM)    (KOHM)   PRES(MB)  FREQ (HZ)

 6 17  0  20 7     22 2     16 36      901 0   1017 71    35299 7  NO WIND,
 0  0  0   0 0      0.0     16 25     1032 0   1017 68    35299 7  CLOUDS FORM-
 0  0  0   0 0      0 0     16 21     1045 0   1017 70    35299 8  ING RAPIDLY
 6 19  0  20 8     22 4     16 19     1073 0   1017 67    35300 0  AT DAWN
 0  0  0   0 0      0 0     16 22     1063 0   1017 66    35299 9  SLIGHT HAZE
 6 20  0  20 6     22 4     16 19     1096 0   1017 52    35260 1  ON MTN

REDUCED DATA

  TIME     DIGITAL DIGIQTZ  DRY  THER     E      E
HR MN SEC  PRESS    PRESS   TEMP TEMP   GRND   HELI

 6 17  0  1017 46 1016 94  22 2 22 3   23 67 22 73
 6 17 40  1017 43 1016 94  22 3 22 6   23 70 23 58
 6 18 20  1017 45 1016 91  22 3 22 7   23 73 23 78
 6 19  0  1017 42 1016 87  22 4 22 8   23 75 23 94
 6 19 30  1017 41 1016 89  22 4 22 7   23 53 23 79
 6 20  0  1017 27 1016 84  22 4 22 8   23 31 24 01
```

LINE #6 LUKE TO PUU NIANIAU JUNE 21,1977

HELICOPTER LINE DATA FLYING FROM PUU NIANIAU

UNCORRECTED DATA

TIME			ALT	VEL	THERM	DIGIQTZ	HYGRIS	COMMENTS
HR	MN	SEC	(KM)	MPH	KOHM	FREQ (HZ)	KOHM	
5	25	0	2 088	45	19 02	36170 4	20 0*	
0	0	0	0 000	0	18 88	36165 9	20 0	
0	0	0	1 768	0	18 28	36138 8	19 8	
5	26	0	0 000	0	18 06	36128 8	19 6	
0	0	0	0 000	0	17.92	36120 5	19 5	
0	0	0	0 000	0	17 80	36108 9	19 3	H
0	0	0	0 000	0	17 78	36103 3	19 1	H
0	0	0	0 000	0	18 00	36095 3	18 3	HIGH
0	0	0	0.000	0	18 01	36079 6	13 8	V
0	0	0	0 000	0	17 83	36054 6	18 6	
0	0	0	0 000	0	17 39	36017 2	18 3	
0	0	0	0 000	0	17 35	35990 5	18 3	
0	0	0	0 000	0	17 36	35982 0	18 5	
0	0	0	0 000	0	17 22	35975 6	18 2	
0	0	0	0 000	0	17 08	35966 6	18 0	HIGH
0	0	0	0.000	0	17 39	35919 9	22 5	
0	0	0	0 000	0	17 46	35900 0	29 3	
0	0	0	0 000	0	17 64	35879 3	46 0	
0	0	0	0 000	0	18 80	35872 9	780 0	
0	0	0	0 000	0	19 13	35850 2	0 0	
0	0	0	0.000	0	19 18	35837 3	1024 0	
5	31	0	1 036	45	19 29	35814 1	836 0	
0	0	0	0 000	0	19 21	35807 7	836 0	
0	0	0	0 000	0	19 16	35800 0	876 0	
0	0	0	0 000	0	19 09	35792.7	889 0	
5	32	0	0 000	0	19 08	35786 3	806 0	HIGH
5	32	15	0.000	0	0 00	35779 8	0 0	
5	32	30	0 914	55	18 92	35767 4	772 0	
0	0	0	0 000	0	18 91	35754 6	740.0	
5	33	0	0 792	55	18 55	35725 1	0 0	
0	0	0	0 000	0.	18 54	35708 2	978.0	
0	0	0	0 000	0	18 54	35699 9	979 0	
0	0	0	0 000	0	18 17	35690 0	0 0	CLOUDS
0	0	0	0 000	0	18 16	35679 7	1179 0	CLOUDS
0	0	0	0 000	0	18 12	35661 3	1188 0	CLOUDS
0	0	0	0 000	0	17 82	35657 2	1260 0	CLOUDS
5	35	0	0 000	0	18 04	35652 6	1196 0	CLOUDS
0	0	0	0 000	0	17 87	35634 2	1211 0	LEVEL OK
0	0	0	0 000	0	17 81	35614 6	1211 0	CLOUD
0	0	0	0 000	0	17 78	35602 9	1200 0	CLOUD
5	36	0	0 000	0	17 77	35595 0	1182 0	OK LEVEL
0	0	0	0 000	0.	17 71	35587 7	1161 0	
0	0	0	0 000	0	17 70	35579 5	1155 0	
0	0	0	0 000	0	17 61	35564 4	1122 0	
0	0	0	0 438	55	17 60	35560 2	1122 0	
0	0	0	0 000	0	17 38	35547 3	1216 0	
0	0	0	0 000	0	17 36	35535 9	1160 0	
0	0	0	0 000	0	17 20	35519 2	1169 0	
5	38	0	0 396	0	17 29	35513 7	1129 0	
0	0	0	0 000	0	17 30	35562 1	1019 0	
0	0	0	0 000	0	17 08	35491 5	1142 0	OVER CLOUDS
0	0	0	0 000	0	17 26	35479 5	845 0	
0	0	0	0 000	0	17 24	35462 3	760 0	

LINE #6 LUKE TO PUU NIANIAU JUNE 21, 1977

UNCORRECTED DATA

TIME			ALT	VEL	THERM	DIGIQTZ	HYGRIS	COMMENTS
HR	MN	SEC	(KM)	MPH	KOHM	FREQ (HZ)	KOHM	
0	0	0	0 000	0	17 04	35452 8	840 0	
5	39	0	0 259	55.	17.05	35443 7	0.0	
0	0	0	0 000	0	17 02	35433 1	702 0	
0	0	0	0 000	0	16 88	35422 5	765 0	
0	0	0	0 000	0	16 90	35104.4	604 0	
0	0	0	0 000	0	16 94	35392 7	605 0	
5	40	0	0 000	0	16 77	35376 0	570 0	
0	0	0	0 122	40	16 79	35369.0	542 0	
0	0	0	0 000	0	16 74	35359 6	542 0	
0	0	0	0 091	35	16 67	35352 1	576 0	
0	0	0	0 076	0.	0 00	35339 8	0 0	LEVELING AT LUKE
0	0	0	0 000	0	0 00	35338 5	0 0	
0	0	0	0 000	0	0 00	35338 2	0 0*	
0	0	0	0 000	0	0 00	35303 9	0 0	LEVELING
5	43	0	0 000	0	16 74	35305 0	576 0	

REDUCED HELICOPTER ATMOSPHERIC DATA

TIME			ADJUSTED	PRESS	TEMP	E	N	COMMENTS
HR	MN	SEC	ALT (KM)	(MB)				
5	25	0	2 00172	807 10	16 2	0 00	225 8	
5	25	20	1 99010	808.20	16 5	0 00	225 8	
5	25	40	1 92027	814 87	17 8	0 00	226 7	
5	26	0	1 89459	817 32	18 3	0 00	227 0	
5	26	16	1 87330	819.36	18 6	0 00	227 3	
5	26	32	1 84362	822 21	18 9	0 00	227 9	H
5	26	48	1 82933	823 59	18 9	0 03	228 2	H
5	27	4	1 80897	825 55	18 4	0 00	229 2	HIGH
5	27	20	1 76921	829 40	18 4	0 00	230 2	V
5	27	36	1 70627	835 54	18 8	0 00	231 6	
5	27	52	1 61283	811 70	19 8	0 00	233 4	
5	28	8	1 54669 -	851 23	19 9	0 00	235 1	
5	28	24	1 52575	853 31	19 9	0 00	235 7	
5	28	40	1 51001	854 88	20 2	0 00	235 8	
5	28	56	1 48791	857 08	20 6	0 00	236 2	HIGH
5	29	12	1 37430	868 49	19 8	0 00	239 9	
5	29	28	1 32646	873.35	19 7	0 24	241 4	
5	29	44	1 27703	878 39	19 3	3 62	243 0	
5	30	0	1 26184	879 95	16 7	15 43	245 1	
5	30	16	1 20837	885 49	16 0	15 10	247 3	
5	30	32	1 17819	888 63	15 9	15 29	248 2	
5	31	0	1 12426	894 27	15 7	14 60	250 1	
5	31	15	1 10836	895 95	15 8	14 76	250 4	
5	31	30	1 08944	897 94	15 9	14 97	250 8	
5	31	45	1 07143	899 84	16 1	15 15	251 2	
5	32	0	1 05548	901 52	16 1	14 93	251 7	HIGH
5	32	15	1 03927	903 24	16 3	15 04	252 0	
5	32	30	1 00953	906 39	16 4	15 15	252 8	
5	32	45	0 98028	909 51	16 4	15 06	253 6	
5	33	0	0 91320	916 67	17 2	16 25	254 9	
5	33	17	0 87497	920 78	17 2	16 60	256 0	
5	33	34	0 85627	922 79	17 2	16 60	256 6	
5	33	51	0 83398	925 19	18 1	17 75	256 5	CLOUDS
5	34	8	0 81032	927 69	18 1	17 99	257 1	CLOUDS

```
LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

REDUCED HELICOPTER ATMOSPHERIC DATA

  TIME      ADJUSTED   PRESS     TEMP      E         N      COMMENTS
HR MN SEC ALT (KM)     (MB)

 5 34 25   0 77631    931 42    18 2    18 11    258 1    CLOUDS
 5 34 42   0 76043    933 15    18 8    19 05    257 9    CLOUDS
 5 35  0   0 75016    934 26    18 3    18 33    258 7    CLOUDS
 5 35 15   0 70921    938 72    18 7    18 82    259 6    LEVEL OK
 5 35 30   0 66579    943.46    18.9    18 99    260 8    CLOUD
 5 35 45   0 63997    946 29    18 9    19 05    261 5    CLOUD
 5 36  0   0 62259    948 20    19 0    19 04    262 0    OK LEVEL
 5 36 15   0 60656    949 97    19 0    19 08    262 4
 5 36 30   0 58859    951 95    19 1    19 18    262 9
 5 36 45   0 55559    955 60    19.3    19 27    263 8
 5 37  0   0 54644    956 61    19 3    19 39    264 0
 5 37 15   0 51835    959 73    19 9    20 24    264 3
 5 37 30   0 49358    962 48    19.9    20 18    265 1
 5 37 45   0 45744    966 51    20 0    20 38    266 0
 5 38  0   0 44557    967 84    20 1    20 32    266 4
 5 38 10   0 42060    970 64    20 0    20 01    267 2
 5 38 20   0 40212    972 71    20 6    21 01    267 2    OVER CLOUDS
 5 38 30   0 37213    976 09    20.1    19 56    268 6
 5 38 40   0 33548    980 23    20 2    19 28    269 7
 5 38 50   0 31529    982 52    20 7    20 21    269.9
 5 39  0   0 29599    984 71    20 6    19 89    270 5
 5 39 12   0 27555    987 03    20 7    19 66    271 1
 5 39 24   0 25506    989 37    21 1    20 39    271 4
 5 39 36   0 21877    993 51    21 0    19 46    272 6
 5 39 48   0 19595    996 13    20 9    19.34    273 4
 5 40  0   0.16268    999 96    21 3    19 62    274 1
 5 40 22   0 14958   1001 47    21 3    19 36    274 6
 5 40 44   0 13144   1003 56    21.4    19 51    275 0
 5 41  6   0 11716   1005.21    21 6    19 98    275 3
 5 41 28   0 09872   1007 35    21.5    19 93    275 9    LEVELING AT LUKE
 5 41 50   0 09603   1007 66    21 5    19 89    276 0
 5 42 12   0 09542   1007 73    21 5    19 84    276 1

MULTIPLICATION CONSTANT 10 HUMPHREYS FORMULA= 0 998507
```

```
LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

RANGE DATA TAKEN AT LUKE
HEIGHT TO THE TOP OF THE TRIBRACH  1017 MM
TOTAL LASER HEIGHT ABOVE THE MARKER  1257 MM
ECCENTRICITY   0MM
DAYLIGHT FILTER  OUT
A 137 MM OFFSET HAS BEEN DIALED INTO THE INSTRUMENT
LINEARITY CORRECTION    7 MM
OBSERVERS  CARTER,SUTTON,WOLFE

UNCORRECTED RANGE DATA

  TIME        RANGE       FREQ    BATTERY THERM        COMMENTS
HR MN SEC   (METERS)      DIFF    VOLTAGE (KOHM)

 5 23   0   28841 230    -4 0    12 540    0 000
 0  0   0   28841 230     0 0     0 000    0 000
 5 32   0   28841 239     0 0     0 000    0 000
 0  0   0   28841 230    -5 0    12 520    0 000
 0  0   0   28841 236     0 0     0 000    0 000
 0  0   0   28841 242     0 0     0 000    0 000
 0  0   0   28841 227     0 0     0 000    0 000
 0  0   0   28841 225     0 0     0 000    0 000
 0  0   0   28841 232     0 0     0 000    0 000
 0  0   0   28841 232     0 0     0 000    0 000
 0  0   0   28841 232     0 0     0 000    0 000
 0  0   0   28841 222     0 0     0 000    0 000
 0  0   0   28841.242     0 0     0 000    0 000
 0  0   0   28841 240     0 0     0 000    0 000
 5 36   0   28841 236    -5 0    12 520    0 000
 0  0   0   28841 227     0 0     0 000    0 000
 0  0   0   28841 227     0 0     0 000    0 000
 0  0   0   28841 233     0 0     0 000    0 000
 5 48   0   28841 234    -5 0    12 510    0 000

REDUCED RANGE DATA IN METERS

  TIME      FREQUENCY     REDUCED    COMMENTS
HR MN SEC   CORRECTED      RANGE

 5 23   0   28841 216    28842 959
 5 27  30   28841 216    28842 960
 5 32   0   28841 226    28842 969
 5 32  20   28841 218    28842 961
 5 32  40   28841 224    28842 967
 5 33   0   28841 230    28842.973
 5 33  20   28841 215    28842 958
 5 33  40   28841 213    28842 956
 5 34   0   28841 220    28842 963
 5 34  20   28841 220    28842 963
 5 34  40   28841 220    28842 963
 5 35   0   28841 210    28842 953
 5 35  20   28841 220    28842 963
 5 35  40   28841 228    28842 971
 5 36   0   28841 221    28842 967
 5 39   0   28841 215    28842 958
 5 42   0   28841 215    28842 958
 5 45   0   28841 221    28842 964

LINE #6 LUKE TO PUU NIANIAU   JUNE 21,1977

MEAN LINE LENGTH WITHOUT ATMOSPHERIC CORRECTIONS=  28841 219 METERS
MEAN CORRECTED LINE LENGTH=  28842 962 METERS
STANDARD DEVIATION=  0054 METERS
STANDARD DEVIATION OF THE MEAN=  0013 METERS
MEAN REFRACTIVE NUMBER= 249 13
```

SAMPLE OUTPUT OF QUADRILATERAL ADJUSTMENTS

PRECEDING PAGE BLANK NOT FILMED

```
ADJUSTMENT OF LUKE QUADRILATERAL WITH DIAGONALS AND CENTER POINT ARPA=3034.34

MEASURED LINE LENGTHS
AB= 31 251588
AC= 28 768443
AD=  3.272860
AE= 20 686788
BC=  7 214161
BD= 30 131599
BF= 10 871607
CD= 26 983473
CE=  8 641175
DE= 19 332759

CALCULATED ANGLES (RADIANS):              CALCULATED ANGLES (DEGREES)

GAMMA 1-4                                 GAMMA 1-4.
     0 117186247E+01                        67    8  33 985
     0 110856060E+01                        63   30  57.037
     0 190515144E+01                       109    9  25 693
     0 209760642E+01                       120   11   2 381
ALPHA 1-4                                 ALPHA 1-4
     0 945486288E+00                        54   10  20 546
     0 100257509E+00                         5   44  39 596
     0 180665298E+01                       103   30  48 927
     0 228136919E+00                        13    4  16 617
BETA 1-4.                                 BETA 1-4
     0 226379077E+00                        12   58  14 036
     0 100830429E+01                        57   46  17 689
     0.984999493E-01                         5   38  37 073
     0 186947268E+01                       107    6  46 419
DELTA 1-4                                 DELTA 1-4
     0 107096239E+01                        61   21  41 850
     0 192871624E+00                        11    3   2 628
     0 150238923E+01                        86    4  50.024
     0 176104279E+00                        10    5  24 115
THETA 1-4                                 THETA 1-4.
     0 100904448E+00                         5   46  53 036
     0 915684468E+00                        52   27  53 479
     0 402763160E+00                        23    4  35 865
     0 192149787E+01                       110    5  37 386
PHI 1-4                                   PHI 1-4
     0 284781658E+01                       163   10   4 335
     0 723518951E+00                        41   27  16 496
     0 256272521E+01                       146   50   0 020
     0 149132392E+00                         8   32  40 764


ANGLE CONDITION CLOSURES (RADIANS):
 1. -0 4382E-05 =  -0.904"
 2   0 1221E-04 =   2 518"
 3  -0 5772E-05 =  -1 190"

NORMALS TO LINES (KM)

KAB=  2 188100
KBC= 18 493254
KCD=  1 870416
KAD=  7 904133
KAC= -1 925249
KBD= -2 067996
KAB2= -2 083849
KBC2= -8 620965
```

```
KAC2= -2 588784
KAE2=  1 161865
KBE2=  1 846198
KCE2=  2 656267
KBC3= -8.620965
KBD3= -1.005518
KCD3= -3 387011
KBE3=  0 942579
KCE3=  3.577188
KDE3=  0 778910

INVERSE WEIGHTS OF LINES.
PAB=    1 000
PBC=    1 000
PCD=    1 000
PAD=    1 000
PAC=    1 000
PBD=    1 000
PAE=    1.000
PBE=    1 000
PCE=    1 000
PDE=    1.000

CORRELATES
 -0 322236737E-05
  0 895756309E-05
 -0.278095789E-05


CORRECTIONS TO LINES (MM).
VAB=    -5 8
VBC=    -0 9
VCD=    -0 9
VAD=    -0 4
VAC=    -1.8
VBD=     4 3
VAE=     7 7
VBE=     1 9
VCE=     2 6
VDE=    -3 6

SUM VV=   139 502
CHECK ON SUM VV=   139 502
SIGMA=  6 819 MM/LINE

ADJUSTED LINE LENGTHS (KM)
AB= 31 251582
BC=  7 214160
CD= 26 983472
AD=  3 272860
AC= 28 768441
BD= 30 131603
AE= 20 686796
BE= 10 871609
CE=  8 641178
DE= 19 332755

CHECK OF CORRECTIONS
 1 -0 27756E-16
 2  0 10747E-06
 3. 0 40439E-05
```

```
ADJUSTED ANGLES (RADIANS).                 ADJUSTED ANGLES (DEGREES).

GAMMA 1-4                                  GAMMA 1-4.
     0.117186565E+01                        67    8   34 641
     0 110856111E+01                        63   30   57 143
     0 190515237E+01                       109    9   25 885
     0 209760617E+01                       120   11    2 331
ALPHA 1-4'                                 ALPHA 1-4
     0 945486525E+00                        54   10   20.595
     0 100257617E+00                         5   44   39 618
     0 180665242E+01                       103   30   48 811
     0 228136782E+00                        13    4   16 589
BETA 1-4                                   BETA 1-4
     0.226379122E+00                        12   58   14 046
     0 100830350E+01                        57   46   17 525
     0 984999572E-01                         5   38   37.075
     0 186946939E+01                       107    6   45 741
DELTA 1-4                                  DELTA 1-4.
     0 107095870E+01                        61   21   41 090
     0 192876475E+00                        11    3    3 629
     0 150238932E+01                        86    4   50 042
     0 176104320E+00                        10    5   24 123
THETA 1-4                                  THETA 1-4
     0 100906943E+00                         5   46   53 551
     0 915684639E+00                        52   27   53 515
     0 402763052E+00                        23    4   35 843
     0 192150185E+01                       110    5   38 207
PHI 1-4                                    PHI 1-4
     0 284780924E+01                       163   10    2 820
     0 723518692E+00                        41   27   16 443
     0 256272528E+01                       146   50    0 034
     0 149132098E+00                         8   32   40.703

ANGLE CONDITION CLOSURES AFTER ADJUSTMENT (RAD).
 1.  0 2910E-10 =    0 000"
 2.  0 1164E-09 =    0 000"
 3:  0 2037E-09 =    0 000"

TRIANGLE CONDITION CLOSURES.
   0 000"
   0 000"
   0 000"
   0 000"
   0 000"
```

APPENDIX II

INSTRUCTIONS FOR THE USE OF DATA 1

I INTRODUCTION

DATA1 was developed to compute marker-to-marker distances from laser ranging data The corrections are dependent upon the instruments used and adjustments would be necessary if any instrument changes are made Distance measurements are taken with a RANGEMASTER II Special measurements of the laser frequency and/or resistance of a thermistor attached to the Rangemaster oscillator and the battery voltage were taken prior to 1978 At that time a new, more stable oscillator was installed, eliminating the need for the special measurements Digital barometers and mercury thermometer psychrometers are used for measured atmospheric conditions on the ground In the case that a helicopter collects atmospheric data along the line it should be equipped with a pressure transducer, a thermistor, and a hygristor These are calibrated against ground instruments just before take-off and after landing

An explanation of all equations and corrections to reduce measured distance to marker-to-marker distance is written out at the top of the computer printout

DATA1 was written by Jerry Carter and the Kynetics plotting subroutines were written by J E Wolfe

II DATA CARDS

The first card of the data determines whether or not reductions will be made and which plots will be generated

Columns	Field	Description
1-3	I3	DEBUG If 999 only uncorrected data will be printed out If 099 all data, corrected and uncorrected will be printed out If blank " " all uncorrected data and reduced data between and including data with stars (*) in the appropriate column will be printed out
		PLOT OPTIONS (Plot generated if option = 1)
5	I1	Uncorrected range vs time
7	I1	Uncorrected wet temp vs time
9	I1	Uncorrected dry temp vs time
11	I1	Uncorrected pressure vs time
13	I1	Digiquartz frequency vs time
15	I1	Thermistor resistance vs time
17	I1	Hygristor resistance vs time
19	I1	Altitude vs time

Columns	Field	Description
21	I1	Reduced ground temperature vs time
23	I1	Reduced ground pressure vs time
25	I1	Ground vapor pressure vs time
27	I1	Ground group refractive number vs time
29	I1	Helicopter temperature vs altitude
31	I1	Helicopter vapor pressure vs altitude
33	I1	Helicopter group refractive number-- linear term vs altitude
35	I1	Helicopter group refractive number vs time
37	I1	Range vs time

Cards 2, 3, and 4 contain constants used in the reduction equations and will generally remain unchanged Card 2 contains the constants for conversion of thermistor resistance to temperature

$$T = 1/(A + B \ln RTH1 + C(\ln RTH1)^3) \text{ where } RTH1 = RTH/R25$$

Columns	Field	Constant
1-10	E10 6	A
16-25	E10 6	B
31-40	E10 6	C
46-51	F6 3	R25

The constants for hygristor resistance to water vapor pressure are read in from card 3

$$\% \text{ relative humidity} = D + E \log RHG1 + F(\log(RHG1))^2$$

RHYG1 = normalized and calibrated hygristor resistance

Columns	Field	Constant
1-6	F6 3	D
11-15	F5 2	E
21-28	F8 4	F

Card 4 has the constants for Digiquartz frequency conversion to pressure on it

$$\text{Pressure} = G(1 - \text{freq} /s) - T(1-\text{freq} /s)^2$$

Helicopter velocity correction

$$\text{Pressure} = \text{pressure } (1 + Q(\text{air speed}) + (R(\text{air speed}/1012)^2)$$

Columns	Field	Constant
1-8	F8 2	G
11-18	F8 2	T
21-29	E9 6	Q
31-39	E9 6	R

s is read in separately for each line and is the "0" pressure frequency as obtained through calibration by comparison with ground station (see 4 helicopter calibration data card 2, col 47-53)

After the atmospheric constants at the beginning of the data set, the actual line data are arranged in the following groups

1 Header card--this will appear at the top of every page and at the top of the plots Information which should be on the header includes line number, description, and date (e g LINE #5 PIER TO ARPA JULY 7, 1977)

2 Laser station atmospheric data+

Card #	Columns	Field	Description
1	1-2	A2	BA, Base atmospheric data ID
2	1-2	A2	BA
	4-9	3I2	Day, Month, Year
	11-22	4A3	Location
	24-29	F6 2	Elevation (meters)
	31	I1	Psychrometer #
	33	I1	Barometer #
	35-38	F4 2	Barometer correction (mbar)
	40-54	5A3	Observers
3 to N	1-2	A2	BA
	4-9	3I2	Hour, minute, second
	11-13	F3 1	Wet temperature (°C)
	15-17	F3 1	Dry temperature (°C)
	19-24	F6 2	Pressure (mbar)
	25	A1	Star (*)
	26-52	9A3	Comments

+Note In the event that ground atmospheric stations have been set up along the line they will follow this format

3 Reflector station atmospheric data

Card #	Columns	Field	Description
1	1-2	A2	RE, Reflector atmospheric data ID
2	1-2	A2	RE
	4-9	3I2	Day, month, year
	11-22	4A3	Location
	24-29	F6 2	Elevation (meters)
	31-34	F4 0	Reflector height to the top of the tribrach (mm)
	36-38	F3 0	Correction for reflector configuration (mm)
	40-41	I2	# of reflectors
	43-44	I2	Eccentricity (mm, correction for setup error over marker)
	46	I1	Psychrometer #
	48	I1	Barometer #
	50-53	F4 2	Barometer correction (mbar)
	55-78	8A3	Observers
3 to N	1-2	A2	RE
	4-9	3I2	Hour, minute, second
	11-13	F3 1	Wet temperature (°C)
	15-17	F3 1	Dry temperature (°C)
	19-24	F6 2	Pressure (mbar)
	25	A1	Star (*)
	26-52	9A3	Comment

4 Helicopter calibration data

Card #	Columns	Field	Description
1	1-2	A2	HC, Helicopter calibration data ID
2	1-2	A2	HC
	4-9	3I2	Day, month, year
	11-22	4A3	Location
	24-32	3A3	INITAL, MIDDLE, or FINAL calibration
	33	I1	Psychrometer #
	35	I1	Barometer #
	37-40	F4 2	Barometer correction (mbar)
	42-45	F4 2	Calibration resistance (kohm)
	47-53	F7 2	Zero pressure frequency (Hz)
	55-70	5A3	Observer
3 to N	1-2	A2	HC
	4-9	3I2	Hour, minute, second
	11-13	F3 1	Wet temperature (°C)
	15-17	F3 1	Dry temperature (°C)
	19-24	F6 2	Pressure (mbar)
	26-29	F4 2	Thermistor resistance (kohm)
	31-36	F6 1	Frequency (Hz)
	38-42	F5 1	Hygristor resistance (kohm)
	44-52	3A3	Comments

This section must precede the helicopter atmospheric data section

5 Helicopter atmospheric data

Card #	Columns	Field	Description
1	1-2	A2	HA, Helicopter atmospheric data ID
2	1-2	A2	HA
	4-9	3I2	Day, month, year
	11-22	4A3	Starting point
	24-35	4A3	Ending point
3 to N	1-2	A2	HA
	4-9	3I2	Hour, minute, second
	11-15	I5	Altimeter reading (ft)
	17-19	F3 0	Airspeed (MPH)
	21-24	F4 2	Thermistor resistance (kohm)
	26-31	F6 1	Digiquartz frequency (Hz)
	33-37	F5 1	Hygristor resistance (kohm)
	38	A1	Star (*)
	39-59	7A3	Comments

6 Laser range data

Card #	Columns	Field	Description
1	1-2	A2	BR, Base station range data ID
2	1-2	A-2	BR
	4-9	3I3	Day, month, year
	11-22	4A3	Location
	24-27	F4 0	Height to the top of the tribrach (mm)
	29-31	A3	Daylight filter--IN or OUT
	33-35	F3 0	Linearity correction (mm)
	37-38	I2	Eccentricity (mm, correction for setup error over marker)
	40-63	8A3	Observers

Card #	Columns	Field	Description
3 to N	1-2	A2	BR
	4-9	3I2	Hour, minute, second
	11-19	F9 3	Range (meters)
	21-24	F4 1	Laser frequency (last 3 digits plus tenths only) (Hz)
	26-30	F5 3	Battery voltage
	32-36	F5 3	Thermistor resistance (kohm)
	37	A1	Star (*)
	38-61	8A3	Comments
N + 1	1-2	A2	GO, signals the end of the line

After the GO statement, the next line (starting with the header card) is inserted After the GO statement of the last line put PAU in the first three (3) columns of the next card PAU means all done in the Hawaiian language and signifies the end of the data

In all instances where data are given, both the first and last data points must be included

When atmospheric data are taken at intermediate ground stations along a line (different from the laser and reflector locations) to determine the refractive index, the subroutines require the same ID number for data reduction (see 2 "laser station atmospheric data") However, the use of the same ID prevents the program from distinguishing the different locations if the data input card sets are placed consecutively Therefore in order to achieve separation a card with RR in the first two columns is required between two stations, that otherwise carry the same ID (B4 in this case) The computer then will print out a new header that includes the location name, line name, etc

This situation occurs any time two different sections of data are placed consecutively with the same ID Another example of such a case is when the helicopter takes calibration data (the ID being HC in this case) at the beginning of the line (first section) and at the end of the line (second section) and the data are placed consecutively They must therefore be separated by an RR card

APPENDIX III

COMPUTER PROGRAM DATA [1]

```
C***********************************************************************
C
C      THE DATA1 PROGRAM IS FOR USE IN REDUCING ALL DATA COLLECTED
C FROM MAKING DISTANCE MEASUREMENTS WITH A RANGEMASTER II LASER.
C IT IS CAPABLE OF REDUCING ATMOSPHERIC MEASUREMENTS MADE EITHER ON
C THE GROUND OR BOTH ON THE GROUND AND IN THE AIR. THE RESULT IS A
C SINGLE MARKER-TO-MARKER LINE LENGTH. AN EXPLANATION OF THE CORR-
C ECTION EQUATIONS USED IS WRITTEN OUT AT THE TOP OF THE COMPUTER
C PRINTOUT. INSTRUCTIONS FOR THE USE OF DATA1 AND THE DATA FORMATS
C MAY BE FOUND UNDER SEPARATE COVER IN "INSTRUCTIONS FOR THE USE OF
C DATA1."
C     DATA1 WAS WRITTEN BY JERRY CARTER IN 1977 FOR USE IN REDUCING
C DATA COLLECTED UNDER THE NASA PROJECT "CRUSTAL DEFORMATION" IN
C SUPPORT OF HALLAKALA LUNAR LASER RANGING GRANT# NSG7179. ALL
C XYNETICS PLOTTING SUBROUTINES WERE WRITTEN BY J. E. WOLFE. THIS
C VERSION IS WORKABLE ON A HARRIS COMPUTER.
C
C                 HAWAII INSTITUTE OF GEOPHYSICS
C                 2525 CORREA ROAD
C                 HONOLULU, HAWAII         96822
C
C***********************************************************************

      BLOCK DATA
      INTEGER BR,BA,RE,HC,HA,CO,DEBUG
      INTEGER HR(200),MN(200),SEC(200)
      INTEGER DA(200),MO(200),YR(200),H(80)
      COMMON /LASER/BR,BA,RE,HC,HA,CO,HR,MN,SEC,DEBUG,NUM,
     2DA,MO,YR,H,NTITLE,IPLOT(17),IR,NMO(200)
      DATA BR/'BR'/,BA/'BA'/,RE/'RE'/,HC/'HC'/,
     2HA/'HA'/,CO/'CO'/,IR/'RR'/
      END
      COMMON /LASER/BR,BA,RE,HC,HA,CO,HR,MN,SEC,DEBUG,NUM,
     2DA,MO,YR,H,NTITLE,IPLOT(17),IR,NMO(200)
      INTEGER BR,BA,RE,HC,HA,CO,DEBUG
      INTEGER OB(9),LOC(4),H(80),HR(200),MN(200),SEC(200),PSY,BAR,
     2CONFIG,ECC,DA(200),MO(200),YR(200),ECD,IBUFF(26)
      REAL IH,P(2,2,6),Y(2,2),ELE(2),PRE(6),TEM(6),HUM(6),ALT(200),
     2REF(200),LIN
      DATA PAU/'P'/,IN/'IN '/,BLANK/' '/
      IFLAG=0
      CALL PLOTS (ND,NE,1)
C
C PSYCHROMETER CORRECTIONS
C
      P(1,1,1)=-.014
      P(2,1,1)=1.001
      P(1,2,1)=-.175
      P(2,2,1)=1.000
      P(1,1,2)=-.023
      P(2,1,2)=1.005
      P(1,2,2)=-.187
      P(2,2,2)=1.009
      P(1,1,3)=.153
      P(2,1,3)=.995
      P(1,2,3)=-.425
      P(2,2,3)=1.008
      P(1,1,4)=-.276
      P(2,1,4)=1.016
      P(1,2,4)=0.274
      P(2,2,4)=0.995
      P(1,1,5)=0.480
      P(2,1,5)=0.969
```

```
      P(1,2,5)=-.416
      P(2,2,5)=0.983
      P(1,1,6)=-.399
      P(2,1,6)=1.021
      P(1,2,6)=0.062
      P(2,2,6)=1.002
C
C READS AND WRITES ATMOSPHERIC CALIBRATION CONSTANTS
C
      READ(25,102) DEBUG,(IPLOT(I),I=1,17)
 102  FORMAT(I3,17(1X,I1))
      READ(25,106) A,B,C,R25
 106  FORMAT(3(E10.6,5X),F6.3)
      READ(25,107) D,E,F
 107  FORMAT(F6.3,4X,F5.2,5X,F8.4)
      READ(25,108) G,T,Q,R
 108  FORMAT(2(F8.2,2X),E9.6,1X,E9.6)
      WRITE(6,1)
    1 FORMAT('1',17X,'EXPLANATION OF CORRECTIONS',//,
     2'     EACH DATA SET IS NUMBERED BY PAGE WITH THE LINE NUMBER,',/,
     3' ENDPOINTS, AND DATE WRITTEN AT THE TOP OF THE PAGE.  DATA ',/,
     4' SETS OR "LINES" ARE COMPOSED OF SEVERAL SECTIONS.  THE FIVE',/,
     5' DIFFERENT SECTIONS, 1) ATMOSPHERIC DATA AT THE LASER, 2)',/,
     6' ATMOSPHERIC DATA AT THE REFLECTORS, 3) HELICOPTER CALI-',/,
     7' BRATION DATA, 4) HELICOPTER ATMOSPHERIC DATA, AND 5) RANGE',/,
     8' DATA, ARE FURTHER DIVIDED INTO TWO SUBSECTIONS, UNCORRECTED',/,
     9' AND REDUCED DATA.  THE UNCORRECTED DATA IS LISTED AS IT WAS',/,
     1' WRITTEN IN THE FIELD.  STARS (*) IN THE ROWS INDICATE THE',/,
     1' BEGINNING AND ENDING POINTS TO BE USED IN REDUCING THE DATA ',/,
     2' ALL DATA , EXCEPT RANGE DATA, ARE LINEARLY INTERPOLATED ',/,
     3' BEFORE ANY REDUCTIONS ARE DONE.  MISSING RANGE VALUES ARE ',/,
     5' EXCLUDED FROM THE LINE.  TIMES AND DATES ARE LOCAL (GMT-10)',/)
      WRITE(6,3)
    3 FORMAT('0',15X,'DIGITAL BAROMETER CORRECTIONS',//,
     2'     ALL DIGITAL BAROMETERS HAVE BEEN CALIBRATED IN 20 TO 25',/,
     3' MILLIBAR STEPS.  THE CORRECTION APPLIED FOR THE PRESSURE ',/,
     4' RANGE OBSERVED IS WRITTEN ABOVE THE UNCORRECTED DATA',/)
      WRITE(6,4)(K,((P(I,J,K),I=1,2),J=1,2),K=1,6)
    4 FORMAT('0',18X,'PSYCHROMETER CORRECTIONS',//,
     2'     LINEAR CORRECTIONS FOR EACH THERMOMETER WERE CALCULATED',/,
     3' FROM A CALIBRATION AGAINST OSU THERMOMETERS.  THE TRUE TEMP-',/,
     4' ERATURE T=A+BM (M=MEASURED TEMPERATURE)   ',/,
     5/,23X,'A',6X,'B',11X,'A',6X,'B',/,6(' PSYCHROMETER #',I1,
     5' WET ',2(F6.3,1X),' DRY ',2(F6.3,1X),/))
      WRITE (6,5)
    5 FORMAT('0',13X,'CONVERSION OF GROUND TEMPERATURES',/,
     213X,'AND PRESSURE TO WATER VAPOR PRESSURE',//,
     3' E=ESAT-.00066(1+.00115(TWET))(TDRY-TWET)P',//,
     5' E=WATER VAPOR PRESSURE (MBAR)',/,
     6' ESAT=269782133 EXP(-4271.071252/(TWET+242.625))',/,
     6'      =A LEAST SQUARES FIT TO THE SMITHSONIAN PSYCHROMETRIC',/,
     7'        TABLES FROM 0 TO 25 DEGREES C ',/,
     8' TWET=WET THERMOMETER TEMPERATURE (DEG.C)',/,
     9' TDRY=DRY THERMOMETER TEMPERATURE (DEG.C)',/,
     1' P=PRESSURE (MBAR)',/)
      WRITE(6,7) A,B,C,R25,R25
    7 FORMAT('0',19X,'HELICOPTER TEMPERATURE',/,
     111X,' CALCULATED FROM THERMISTOR RESISTANCE',
     2//,' T-1/(',F9.8,'+',F10.9,'LN(RTH1)+',F12.11,'(LN(RTH1))**3)',//,
     4' T=TEMPERATURE (DEG K)',/,
     5' RTH1=RTH/',F6.3,/,
     6' RTH=THERMISTOR RESISTANCE (KOHM)',/,
     71X,F6.3,'=CALIBRATION RESISTANCE AT 25 DEG. C (KOHM)',/)
      WRITE(6,8) G,T,R,Q
```

```
 8 FORMAT('0',3X,'CONVERTING HELICOPTER DIGIQUARTZ FREQUENCY TO PRESS
  1URE',//,
  2' P=',F8 2,'(1-FREQ/F)-',F7.2,'(1-FREQ/F)**2',/,
  3'  =PRESSURE FROM DIGIQUARTZ TRANSDUCER (MBAR)',/,
  4' FREQ=DIGIQUARTZ FREQUENCY (HZ)',/,
  5' F=ZERO PRESSURE FREQUENCY (HZ). F IS CALCULATED FOR EACH',/,
  6'   LINE BY COMPARISON WITH GROUND INSTRUMENTS AND IS WRITTEN',/,
  7'   IN THE HELICOPTER CALIBRATION SECTION ABOVE THE UNCOR-',/,
  7'   RECTED DATA',/,
  9 ' PRES=P+P((',F8 7,')(V**2)/1012-',F8 7,'(V))',/,
  2'      =VELOCITY CORRECTED PRESSURE (MBAR)',/,
  8' V=HELICOPTER AIRSPEED (MPH)',/)
   WRITE(6,9) D,E,F
9  FORMAT('0',12X,'CALCULATION OF WATER VAPOR PRESSURE',/,
  213X,'FROM HELICOPTER HYGRISTOR RESISTANCE',//,
  3' E=(ESAT)(%RH)/100',//,
  4' E=WATER VAPOR PRESSURE (MBAR)',/,
  6' ESAT=269782133 EXP(-4271 071252/(TWET+242 625))',/,
  6'      =LEAST SQUARES FIT TO THE SMITHSONIAN PSYCHROMETREC',/,
  6'       TABLES FROM 0 TO 25 DEGREES C',/,
  7' T=TEMPERATURE (DEG  C)',/,
  8' %RH=',F5 2,'+',F5 2,'(R)',F6 2,'(R)(R)',/,
  9'     =LEAST SQUARES FIT TO THE PUBLISHED PERCENT RELATIVE',/,
  1'      HUMIDITY CURVE',/,
  1' R=LOG((CALIB)(CRES))',/,
  2' CALIB=1-(1-H)(1-T/25)',/,
  3'       =LINEARLY INTERPOLATED TEMPERATURE CORRECTION TO THE',/,
  4'        25 DEG  C CURVE',/,
  6' H=.98599- 36991(LOG(CRES))+.11159(LOG(CRES))**2',/,
  6'  =LEAST SQUARES FIT TO THE TEMPERATURE CORRECTION CURVES',/,
  7'   FROM 0 TO 25 DEGREES C ',/,
  8' CRES=RHYG/R33',/,
  9'      =NORMALIZED HYGRISTOR RESISTANCE',/,
  9' RHYG=HYGRISTOR RESISTANCE (KOHM)',/,
  1' R33=HYGRISTOR RESISTANCE AT 33% RELATIVE HUMIDITY AND 25',/,
  1'      DEGREES C  R33 IS DETERMINED FOR EACH LINE AND PRINTED',/,
  2'      ABOVE THE HELICOPTER CALIBRATION DATA ',/)
   WRITE(6,10)
10 FORMAT('0',14X,'HELICOPTER ALTITUDE CALCULATION',/,
  2 18X,' USING HUMPHREYS FORMULA',//,
  3' ALT=LOALT+(18.4(LOG(LOP/P))(1+ 00367(LOT+T)/2)',/,
  4'      (1+ 378((LOE/LOP+E/P)/2))1 001958(1+2(LOALT)/6371)',//,
  4' ALT=ALTITUDE DIFFERENCE BETWEEN THE POINT AND THE STARTING',/,
  5'      MARKER (KM)',/,
  6' LOALT=PREVIOUSLY CALCULATED ALTITUDE DIFFERENCE (KM)',/,
  7' LOP=PRESSURE AT PREVIOUS ALTITUDE (MBAR)',/,
  7' P=PRESSURE (MBAR)',/,
  8' LOT=TEMPERATURE AT PREVIOUS ALTITUDE (DEG  C)',/,
  9' T=TEMPERATURE (DEG  C)',/,
  1' LOE=WATER VAPOR PRESSURE AT PREVIOUS ALTITUDE (MBAR)',/,
  1' E=WATER VAPOR PRESSURE (MBAR)',/,
  4'    WHEN THE END OF THE LINE IS REACHED, THE DIFFERENCE BET-',/,
  6' WEEN THE CALCULATED ENDPOINT ELEVATION AND ITS KNOWN ELE-',/,
  5' VATION IS PRORATED ALONG THE LINE  THIS IS THE SAME AS IF',/,
  7' THE CONSTANT 18 4 WERE MULTIPLIED BY A FACTOR HC (SHOWN ',/,
  7' BELOW).  AS A MEASURE OF THE CORRECTION APPLIED HC IS ',/,
  8' PRINTED AT THE END OF THE REDUCED HELICOPTER DATA ',/,
  3' HC=DELTAE/MALT',/,
  6' DELTAE=KNOWN ELEVATION DIFFERENCE BETWEEN MARKERS',/,
  7' MALT=CALCULATED ENDPOINT ELEVATION DIFFERENCE',/,
  1'    THE ALTITUDES PRINTED OUT IN THE UNCORRECTED HELICOPTER',/,
  2' DATA ARE READ FROM THE HELICOPTER ALTIMETER. THOSE IN THE',/,
  3' REDUCED DATA SECTION ARE THE ADDITION OF THE STARTING BENCH-',/,
  4' MARK ELEVATION AND THE ALTITUDE DIFFERENCE FROM THAT MARKER ',/)
```

```
      WRITE(6,6)
 6    FORMAT('0',14X,'COMPUTATION OF REFRACTIVE NUMBER',//,
     2' N=(300 2(P)-41.8(E))/(3 709(T))',//,
     3' N=REFRACTIVE NUMBER=(REFRACTIVE INDEX-1)10**6',/,
     4' P=PRESSURE (MBAR)',/,
     5' E=WATER VAPOR PRESSURE (MBAR)',/,
     6' T=DRY TEMPERATURE (DEG K)',/)
      WRITE(6,11)
11    FORMAT('0',17X,'LASER FREQUENCY CORRECTION',//,
     2' D=DM(14984980)/F',//,
     3' D=FREQUENCY CORRECTED DISTANCE (M)',/,
     4' DM=MEASURED DISTANCE (M)',/,
     5' F=FREQUENCY MEASURED (HZ)  NOTE  IN THE UNCORRECTED RANGE',/,
     6'    DATA THE FREQUENCY DIFFERENCE IS LISTED  THIS IS THE',/,
     7'    MEASURED FREQUENCY MINUS THE FREQUENCY ASSUMED BY THE ',/,
     8'    INSTRUMENT (14984980 HZ)  IF THE FREQUENCY IS NOT MEASURED',/,
     4'    DIRECTLY, THE FREQUENCY DIFFERENCE MAY BE CALCULATED FROM',/,
     5'    AN EMPIRICAL RELATIONSHIP INVOLVING THE BATTERY VOLTAGE AND',/
     6'    THE RESISTANCE OF A THERMISTOR ON THE OSCILLATOR',/,
     2' FD=2 7(BV-12 5)-84 3+12 73(RTH)- 434524(RTH)(RTH)',/,
     4'    =FREQUENCY DIFFERENCE (HZ)',/,
     6' BV=BATTERY VOLTAGE',/,
     6' RTH=THERMISTOR RESISTANCE (KOHM)',/)
      WRITE(6,13)
13    FORMAT('0',20X,'LINEARITY CORRECTION',//,
     2'     THE CORRECTION FOR THE INSTRUMENTS LINEARITY IN THE ',/,
     3' RANGE OF DISTANCES OBSERVED IS PRINTED ABOVE THE UNCOR-',/,
   , 4' RECTED RANGE DATA. THE CORRECTIONS WERE DETERMINED EMPIR-',/,
     5' ICALLY OVER A 10 METER BASE LINE',/)
      WRITE(6,12)
12    FORMAT('0',7X,'DISTANCE REDUCTION TO THE BENCHMARK ELEVATIONS',//,
     2' D=SQRT((DF)(DF)-DD)',//,
     3' D=HEIGHT CORRECTED DISTANCE IN A SPHERICAL SYSTEM (M)',/,
     4' DF=FREQUENCY CORRECTED DISTANCE (M)',/,
     5' DD=2(1-COS(ARCTAN(DF/R)))(R+LOEL)(RH+IH)+2(HIEL-LOEL)',/,
     5'     (RH-IH(COS(ARCTAN(DF/R))))',/,
     7' R=EARTH RADIUS 6371 KM',/,
     8' LOEL=ELEVATION OF THE LOW MARKER (KM)',/,
     8' RH= HEIGHT OF LASER OR REFLECTOR ABOVE THE LOWER MARKER (MM)',/,
     8' IH= HEIGHT OF LASER OR REFLECTOR ABOVE THE UPPER MARKER (MM)',/,
     1' HIEL=ELEVATION OF THE UPPER MARKER (KM)',/)
      WRITE(6,15)
15    FORMAT('0','   ALL OF THE ABOVE CORRECTIONS ARE APPLIED TO THE',/,
     2' DISTANCE MEASUREMENTS AND THE RESULTING VALUES ARE LISTED IN',/,
     3' THE "FREQUENCY CORRECTED" COLUMN OF THE REDUCED RANGE DATA ',/,
     4' THE "REDUCED RANGE" COLUMN IS THE RESULT OF APPLYING THE ',/,
     5' ATMOSPHERIC CORRECTIONS DESCRIBED BELOW TO THE FREQUENCY',/,
     7' CORRECTED VALUE ',/)
      WRITE(6,16)
 16   FORMAT('0',16X,'REFRACTIVE INDEX CORRECTION',//,
     2'     THE MEAN REFRACTIVE NUMBER FOR THE LINE IS CALCULATED',/,
     3' BY NUMERICAL INTEGRATION (TRAPEZOIDAL RULE) OF THE REFRAC-',/,
     3' TIVE NUMBER VS  ALTITUDE CURVE  THIS VALUE IS WRITTEN AT THE',/,
     6' END OF THE CORRECTED RANGE DATA ALONG WITH THE MEAN LINE',/,
     6' LENGTH (MARKER TO MARKER) FOR THE SET OF MEASUREMENTS, THE',/,
     7' STANDARD DEVIATION, AND STANDARD DEVIATION OF THE MEAN ',/,
     8' D=FR(RI)/((RN X 10**-6)+1)',/,
     9'  =DISTANCE CORRECTED FOR REFRACTIVE INDEX',/,
     1' FR=FREQUENCY AND GEOMETRICALLY CORRECTED DISTANCE ',/,
     1' RI=REFRACTIVE INDEX ASSUMED BY THE INSTRUMENT (1 00030984)',/,
     3' RN=THE MEAN REFRACTIVE NUMBER ',/)
      WRITE(6,17)
17    FORMAT('0',17X,'BEAM CURVATURE CORRECTION',//,
     2' DD=-K(1-K)D**3/(24(R)(R))',//,
```

```
     3' DD=BEAM CURVATURE CORRECTION ASSUMING A LINEAR CHANGE IN',/,
     4'     REFRACTIVE NUMBER FROM MARKER TO MARKER ',/,
     5' D=DISTANCE CORRECTED FOR REFRACTIVE INDEX',/,
     5' K=(R)(10**-6)((LON-HIN))/((HIEL-LOEL))',/,
     7' R=EARTH RADIUS 6371 KM',/,
     8' LON=REFRACTIVE NUMBER AT THE LOWER MARKER',/,
     9' HIN=REFRACTIVE NUMBER AT THE UPPER MARKER',/,
     1' HIEL=UPPER MARKER ELEVATION (KM)',/,
     1' LOEL=LOWER MARKER ELEVATION (KM)',/)
C
C READS AND WRITES HEADER
C
  999 NTITLE=2
      K=0
      DO 720 I=1,6
 720  ALT(I)=0
      BUFFER IN (25,IBUFF,S,18,IS)
      DECODE (54,710,IBUFF) (H(I),I=1,54)
  710 FORMAT(54A1)
      DO 701 I=3,54
      IF(H(I).EQ.BLANK.AND.H(I-1).EQ.BLANK.AND.H(I-2).EQ.BLANK)
     2GO TO 711
  701 NTITLE=NTITLE+1
  711 NTITLE=NTITLE-2
      NUM=0
      DECODE (54,712,IBUFF) (H(I),I=1,18)
 712  FORMAT(18A3)
      IF(H(1).EQ.PAU) GO TO 200
C
C CHECKS DATA ID AND BRANCHES TO THE APPROPRIATE SECTION
C
 111  READ(25,115,END=200) IDD
      ID=IDD
 115  FORMAT(A2)
 112  IF(ID.EQ.BR)GO TO 120
      IF(ID.EQ.BA)GO TO 122
      IF(ID.EQ.RE)GO TO 123
      IF(ID.EQ.HC)GO TO 124
      IF(ID.EQ.HA)GO TO 126
      IF(ID.EQ.IR) GO TO 111
      IF(ID.EQ.CO)GO TO 999
C
C READS & WRITES RANGE DATA HEADER
C
 120  READ(25,130) (LOC(I),I=1,4),IH,IFL,LIN,ECC,(OB(J),J=1,8)
 130  FORMAT(10X,4A3,1X,F4.0,1X,A3,1X,F3.0,1X,I2,1X,8A3)
      DUM=IH
      IH=IH+240
      NUM=NUM+1
      WRITE(6,101)(H(I),I=1,18),NUM
 101  FORMAT('1',18A3,13X,'PAGE#',I2)
      WRITE(6,135) (LOC(I),I=1,4),DUM,IH,ECC,IFL,LIN,(OB(J),J=1,8)
 135  FORMAT('0',          'RANGE DATA TAKEN AT ',4A3,/,
     2                                                     ' HEIGHT TO THE T
     3OP OF THE TRIBRACH  ',F5.0,'MM',/,' TOTAL LASER HEIGHT ABOVE ',
     4'THE MARKER. ',
     4F5.0,'MM',/,' ECCENTRICITY  ',I2,'MM',/,' DAYLIGHT FILTER  ',A3,/,
     5' A 137 MM OFFSET HAS BEEN DIALED INTO THE INSTRUMENT',/,
     6' LINEARITY CORRECTION  ',F4.0,'MM',/,
     8             ' OBSERVERS  ',8A3)
      IF (ALT1.LT.ALT2) GO TO 50
      I=IH
      IH=CH
      CH=I
```

```
C
C ECCENTRICITY, LINEARITY, AND REFLECTOR OFFSET CORRECTION
C
 50   CORR=ECC+ECD-40+LIN
      CALL WANGE(ID,ALT,REF,K,IH,CH,CORR,LOC)
      GO TO 112
 122  NUM=NUM+1
      WRITE(6,101)(H(I),I=1,18),NUM
C
C READS & WRITES BASE STATION ATMOSPHERIC HEADER
C
      READ(25,139) DA(1),MO(1),YR(1),(LOC(I),I=1,4),ELE(1),PSY,BAR,BARC,
     1 (OB(J),J=1,5)
 139  FORMAT(3X,3I2,1X,4A3,1X,F6.2,2(1X,I1),1X,F4.2,1X,5A3)
      WRITE(6,140) (LOC(I),I=1,4),ELE(1),PSY,BAR,BARC,(OB(J),J=1,5)
 140  FORMAT('0',      'ATMOSPHERIC DATA TAKEN AT ',4A3,/,' ELEVATION: ',
     2F7.2,'M',       /,' PSYCHROMETER #',I1,3X,'BAROMETER #',I1,/,
     3' BAROMETER CORRECTION  ',F5.2,'MBAR',/,' OBSERVERS  ',5A3)
      ELE(1)=ELE(1)*.001
      ALT1=ELE(1)
      DO 143 I=1,2
      DO 143 J=1,2
      Y(I,J)=P(I,J,PSY)
 143  CONTINUE
      CALL ATMOS(ID,BARC,Y,PR1,TE1,HU1,A5,LOC)
      K=K+1
C
C ARRANGES GROUND DATA IN DESCENDING ORDER
C
      PRE(6)=PR1
      TEM(6)=TE1
      HUM(6)=HU1
      ALT(6)=ELE(1)
      REF(6)=A5
      DO 146 J=1,5
      I1=6-J
      DO 146 I=1,I1
      L=I+1
      IF(ALT(I) .GE. ALT(L)) GO TO 146
      EL=ALT(I)
      ALT(I)=ALT(L)
      ALT(L)=EL
      AL=REF(I)
      REF(I)=REF(L)
      REF(L)=AL
      EL=PRE(I)
      PRE(I)=PRE(L)
      PRE(L)=EL
      EL=TEM(I)
      TEM(I)=TEM(L)
      TEM(L)=EL
      EL=HUM(I)
      HUM(I)=HUM(L)
      HUM(L)=EL
 146  CONTINUE
      ELE(1)=ALT(1)
      ELE(2)=ALT(2)
      GO TO 112
C
C READS AND WRITES REFLECTOR HEADER
C
 123  READ(25,145) DA(1),MO(1),YR(1),(LOC(J),J=1,4),ELE(2),RH,CORR,
     2CONFIG,ECD,PSY,BAR,BARC,(OB(I),I=1,8)
 145  FORMAT(3X,3I2,1X,4A3,1X,F6.2,1X,F4.0,1X,F3.0,1X,2(I2,1X),2(I1,1X),
```

```
     2F4.2,1X,8A3)
      CH=RH+CORR
      NUM=NUM+1
      WRITE(6,101)(H(I),I=1,18),NUM
      WRITE(6,150)    (LOC(J),J=1,4),ELE(2),RH,CORR,CH,
     2CONFIG,LCD,PSY,BAR,BARC,(OB(I),I=1,8)
  150 FORMAT('0','REFLECTOR ATMOSPHERIC DATA TAKEN AT ',4A3,
     2 /,' ELEVATION   ',F7.2,
     3 'M',/,' HEIGHT TO THE TOP OF THE TRIBRACH. ',F5.0,'MM',
     4/,' HEIGHT FROM THE TOP OF THE TRIBRACH',/,'   TO THE CENTER OF TH
     5E REFLECTORS  ',F4.0,'MM',/,' TOTAL REFLECTOR HEIGHT ABOVE THE MAR
     6KER  ',F5.0,'MM',
     6/,' NUMBER OF REFLECTORS  ',I2,/,' ECCENTRICITY  ',I2,
     7'MM',/,' PSYCHROMETER #',I1,3X,' BAROMETER #',I1,/,' BAROMETER COR
     8RECTION  ',F5.2,'MBAR',/,' OBSERVERS  ',8A3)
      ELE(2)=ELE(2)*.001
      ALT2=ELE(2)
      DO 152 I=1,2
      DO 152 J=1,2
      Y(I,J)=P(I,J,PSY)
  152 CONTINUE
      CALL ATMOS(ID,BARC,Y,PR1,TE1,HU1,A5,LOC)
      K=K+1
C
C ARRANGES GROUND DATA IN DESCENDING ORDER
C
      PRE(6)=PR1
      TEM(6)=TE1
      HUM(6)=HU1
      ALT(6)=ELE(2)
      REF(6)=A5
      DO 147 J=1,5
      J1=6-J
      DO 147 I=1,J1
      L=I+1
      IF(ALT(I).GE.ALT(L)) GO TO 147
      EL=ALT(I)
      ALT(I)=ALT(L)
      ALT(L)=EL
      AL=REF(I)
      REF(I)=REF(L)
      REF(L)=AL
      EL=PRE(I)
      PRE(I)=PRE(L)
      PRE(L)=EL
      EL=TEM(I)
      TEM(I)=TEM(L)
      TEM(L)=EL
      EL=HUM(I)
      HUM(I)=HUM(L)
      HUM(L)=EL
  147 CONTINUE
      ELE(1)=ALT(1)
      ELE(2)=ALT(2)
      GO TO 112
  124 CALL CALIBR(ID,P,CALIB,A,B,C,R25,D,E,F,G,T,S)
      GO TO 112
C
C READS & WRITES HELICOPTER LINE HEADER
C
  126 READ(25,165) DA(1),MO(1),YR(1),(LOC(I),I=1,4),(OB(I),I=1,4)
      NUM=NUM+1
      WRITE(6,101)(H(I),I=1,18),NUM
      WRITE(6,170)(LOC(I),I=1,4)
```

```
  165   FORMAT(3X,3I2,1X,4A3,1X,4A3)
  170   FORMAT('0', 'HELICOPTER LINE DATA. FLYING FROM ',4A3)
        CALL H ATM(ID,CALIB,A,B,C,R25,D,E,F,G,T,S,Q,R,ELE,PRE,TEM,HUM,
       2ALT,REF,K,LOC,OB)
        GO TO 112
 200    CALL PLOT (0 ,0.,999)
        STOP
        END

 C*********************************************************************
 C
 C       SUBROUTINE WANGE USES THE PREVIOUSLY CALCULATED REDUCED
 C REFRACTIVE INDICES AND ALTITUDES TO CORRECT THE DISTANCE MEASURE-
 C MENTS FOR THE ATMOSPHERIC CONDITIONS  IT ALSO MAKES ALL NECESSARY
 C ADJUSTMENTS TO REDUCE THE LINE LENGTH TO A MARKER-TO-MARKER DISTANCE.
 C
 C                                PARAMETER LIST
 C    ID     SECTION IDENTIFICATION (BR)
 C    ALT    ARRAY CONTAINING THE ALTITUDES ALONG THE LINE
 C    REF    ARRAY CONTAINING THE REDUCED REFRACTIVE INDICES WHICH
 C            CORRESPOND TO THE ALTITUDES
 C    L      NUMBER OF POINTS ALONG THE LINE
 C    IH     HEIGHT OF THE LASER OR REFLECTOR ABOVE THE LOWER MARKER
 C    CH     HEIGHT OF THE LASER OR REFLECTOR ABOVE THE UPPER MARKER
 C    CORR   CORRECTION TERM WHICH INCLUDES THE PRISM OFFSETS, COMBINED
 C            MEASURED SETUP ERRORS, AND THE LASER LINEARITY CORRECTION
 C    LOC    ARRAY CONTAINING THE LOCATION OF THE STATION
 C
 C*********************************************************************

        SUBROUTINE WANGE(ID,ALT,REF,L,IH,CH,CORR,LOC)
        COMMON /LASER/BR,BA,RE,HC,HA,GO,HR,MN,SEC,DEBUG,NUM,
       2DA,MO,YR,H2,NTITLE,IPLOT(17),IR,NMO(200)
        INTEGER TTL(18),TTY(6),TTA(5),LOC(4)
        INTEGER DA(200),MO(200),YR(200),H2(80)
        INTEGER    BR,BA,RE,HC,    HA,    GO,DEBUG,STAR
        INTEGER HR(200),MN(200),SEC(200),H(9,200),MARK(200)
        DIMENSION RANGE(200),BANG(200)
        DOUBLE PRECISION RANGE,BANG,DIST,DIST2,AVG
        REAL ALT(200),REF(200)
        REAL BATV(200),RTH(200),FREQ(200),IH
        DATA III/' '/,STAR/'*'/
        DATA TTY/'UNC','ORR','ECT','ED ','RAN','GE '/
        DATA TTA/'M +',' CR','APH',' VA','LUE'/
        DO 971 I=1,18
 971    TTL(I)=III
        N1=1
        DIST=0
        K=0
        N=8
        WRITE(6,10)
  10    FORMAT('0','UNCORRECTED RANGE DATA',//,2X,' TIME',5X,
       2' RANGE      FREQ    BATTERY THERM        COMMENTS',/,
       ^' HR MN SEC  (METERS)',
       3 '     DIFF    VOLTAGE (KOHM)',/)
 C
 C READS DATA
 C
  30    READ(25,15)  ID,HR(N1),MN(N1),SEC(N1),RANGE(N1),FREQ(N1),BATV(N1),
       2RTH(N1),MARK(N1),(H(I,N1),I=1,9)
  15    FORMAT(A2,1X,3I2,1X,F9 3,1X,F4 1,1X,F5 3,1X,F5 3,A1,9A3)
        IF(ID NE BR) GO TO 35
        N=N+1
        IF(N1 EQ 47) GO TO 21
```

```
      IF(N.NE.55) GO TO 31
 21   NUM=NUM+1
      WRITE(6,5)(H2(I),I=1,18),NUM
    5 FORMAT('1',18A3,13X,'PAGE+',I2)
      N=0
      WRITE(6,10)
C
C FINDS FREQUENCY DIFFERENCE
C
 31   FREQ(N1)=FREQ(N1)-980
      IF(FREQ(N1).EQ.0.) FREQ(N1)=FREQ(N1)+.0001
      IF (FREQ(N1).EQ.-980.)FREQ(N1)=0.
C
C WRITES UNCORRECTED DATA
C
      WRITE(6,20)HR(N1),MN(N1),SEC(N1),RANGE(N1),FREQ(N1),BATV(N1),
     2RTH(N1),MARK(N1),(H(I,N1),I=1,9)
 20   FORMAT(3(1X,I2),2X,F10.3,2X,F5.1,2X,F6.3,2X,F6.3,A1,1X,9A3)
      N1=N1+1
      GO TO 30
 35   N1=N1-1
C
C INTERPOLATES DATA
C
      CALL INTERP(N1)
      IF(IPLOT(1).NE.1) GO TO 40
      TSCA=3600*HR(N1)+60*MN(N1)-3600*HR(1)-60*MN(1)
      IF(TSCA.LT.0) TSCA=TSCA+86400
      TSCA=.19685/(AINT(TSCA/60))
      CALL MPLOT(N1,RTH, RANGE,TTL,1,TTY,17,TTA,15,TSCA,78.74,1,
     3 MARK,3,LOC,ITL,3)
      CALL PLOT(0.,0.,5)
  40  IF(DEBUG.EQ.999) GO TO 509
      CALL INTERP2(FREQ,N1)
      CALL INTERP2(BATV,N1)
      CALL INTERP2(RTH,N1)
      IF(N.LE.44) GO TO 36
      NUM=NUM+1
      N=-6
      WRITE(6,5)(H2(I),I=1,18),NUM
 36   WRITE(6,60)
      N=N+6
      DO 50 I=1,N1
C
C CHECKS FOR DATA TO BE USED
C
      IF (MARK(I).EQ.STAR) DEBUG=99
      IF (DEBUG.NE.99) GO TO 50
      IF(RANGE(I).EQ.0.) GO TO 50
      DIST=DIST+RANGE(I)
      K=K+1
      YR(K)=YR(I)
      MO(K)=MO(I)
      DA(K)=DA(I)
      HR(K)=HR(I)
      MN(K)=MN(I)
      SEC(K)=SEC(I)
      DO 62 J=1,7
  62  H(J,K)=H(J,I)
      IF(FREQ(I).NE.0.) GO TO 66
      IF(RTH(I).EQ.0.) GO TO 66
C
C COMPUTES FREQUENCY FROM VOLTAGE AND RTH IF NO FREQUENCY MEASUREMENTS
C WERE TAKEN
```

```
C
      FREQ(I)=2.7*(BATV(I)-12 5)+12.73*RTH(I)- 434524*RTH(I)**2-84 3
  66  CONTINUE
C
C FREQUENCY CORRECTION
C
      RANGE(K)=RANGE(I)*14984980./(FREQ(I)+14984980.)
      IF (MARK(I).EQ STAR AND.K GT 1) DEBUG=0
      MARK(K)=0
  50  CONTINUE
      DIST=DIST/K*.001
C
C INSTRUMENT HEIGHT CALCULATION
C
      ELD=ABS(ALT(1)-ALT(L))
      XMIN=AMIN1(ALT(1),ALT(L))
      COSTH=DCOS(DATAN(DIST/(6371.+XMIN)))
      DD2=(1 -COSTH)*2 *(6371.+XMIN)*(CH+IH)+2.*ELD*
     2 (CH-IH*COSTH)
C
C NUMERICAL INTEGRATION OF REFRACTIVE # VS ALTITUDE
C
      AVG=0
      IF(L GT 1) GO TO 114
      AVG=REF(1)
      GO TO 116
 114  DO 115 I=2,L
 115  AVG=AVG+(REF(I)+REF(I-1))*(ALT(I)-ALT(I-1))/2.
      IF(AVG NE 0 ) GO TO 118
      DO 119 I=1,L
119   AVG=AVG+REF(I)
      AVG=AVG/L
      GO TO 116
118   AVG=DABS(AVG/(ALT(1)-ALT(L)))
  60  FORMAT('0','REDUCED RANGE DATA IN METERS',//,2X,' TIME',4X,
     2' FREQUENCY     REDUCED    COMMENTS',/,
     3' HR MN SEC   CORRECTED      RANGE   ',/)
 116  DIST=0                                      - ---
      VAL=IDINT(RANGE(1))
      DD=0
      DIST1=0
      DIST2=0
      DO 80 I=1,K
C
C INSTRUMENT HEIGHT CORRECTION
C
      RANGE(I)=DSQRT(RANGE(I)**2-DD2)+CORR* 001
C
C REFRACTIVE INDEX CORRECTION
C
      BANG(I)=RANGE(I)*1 00030984/(AVG*1.E-6+1 )
      IF(L EQ 1) GO TO 117
C
C BEAM CURVATURE CORRECTION
C
      IF (ALT(L)  EQ  ALT(1)) GO TO 117
      DD=(REF(1)-REF(L))* 006371/(ALT(L)-ALT(1))
      BANG(I)=BANG(I)-DD*(2 -DD)*(BANG(I)* 001)**3*1000 /(24.*6371 **2)
 117  DIST=DIST+BANG(I)-VAL
      DIST1=DIST1+RANGE(I)-VAL
      DIST2=DIST2+(BANG(I)-VAL)**2
      N=N+1
      IF (N LT 55) GO TO 64
      N=0
```

```
      NUM=NUM+1
      WRITE(6,5)(H2(J),J=1,18),NUM
      WRITE(6,60)
C
C WRITES CORRECTED DATA
C
 64   WRITE(6,65) HR(I),MN(I),SEC(I),RANGE(I),BANG(I),(H(J,I),J=1,9)
  65  FORMAT(3(1X,I2),2X,F10.3,2X,F10.3,2X,9A3)
  80  CONTINUE
      DIST2=DSQRT((DIST2-DIST**2/K)/FLOAT(K-1))
      DIST=DIST/K+VAL
      DIST1=DIST1/K+VAL
      DIST3=DIST2/SQRT(FLOAT(K))
      IF(N LE 49) GO TO 85
      NUM=NUM+1
      WRITE(6,5)(H2(J),J=1,18),NUM
  85  WRITE(6,90) DIST1,DIST,DIST2,DIST3,AVG
90    FORMAT('0','MEAN LINE LENGTH WITHOUT ATMOSPHERIC CORRECTIONS= ',
     2F10 3,' METERS',/,
     2' MEAN CORRECTED LINE LENGTH= ',F10 3,' METERS',/,
     2' STANDARD DEVIATION= ',F5 4,' METERS',/,
     3' STANDARD DEVIATION OF THE MEAN= ',F5 4,' METERS',/,
     4' MEAN REFRACTIVE NUMBER= ',F6.2)
      IF(IPLOT(17) NE 1)   GO TO 509
      TSCA=3600*HR(K)+60*MN(K)-3600*HR(1)-60*MN(1)
      IF(TSCA LT 0) TSCA=TSCA+86400
      TSCA= 19685/(AINT(TSCA/60))
      CALL MPLOT(K,RTH,RANGE,TTL,1,TTY,17,TTA,15,TSCA,78 74,1,
     3 MARK,3,LOC,TTL,2)
      CALL SYMBOL (1 0,1 0,0 2,'CORRECT DIST ',0 ,13)
      DIST=DIST/1 0D 01
      ID1=IDINT(DIST)
      D1=ID1
      D2=SNGL(( DIST-DBLE(D1))*1 0D 01)
      CALL NUMBER (3 2,1 0,0 2,D1,0.,-1)
      CALL WHERE(XDISJ,YDISJ,SIZE)
      XDISJ1=XDISJ+(1 /7 )*0 2
      CALL NUMBER (XDISJ1,1 0,0 2,D2,0.,3)
      CALL SYMBOL (4 8,1 0,0 2,212,0 ,-1)
      CALL SYMBOL (5 0,1 0,0 2,78,0 ,-1)
      CALL SYMBOL (5 0,0 89,0 2,96,0 ,-1)
      CALL NUMBER (5 2,1 0,0 2,DIST3,0 ,3)
      CALL SYMBOL (6 1,1 0,0 2,'SD M' ,0 ,4)
      CALL SYMBOL(4 8,0 5,0 2,77,0 ,-1)
      CALL SYMBOL (5 0,0 5,0 2,78,0 ,-1)
      CALL SYMBOL (5 0,0 39,0 2,96,0 ,-1)
      CALL NUMBER (5 2,0 5,0 2,DIST2,0 ,3)
      CALL SYMBOL (6 1,0 5,0 2,'SD Y)',0 ,5)
      CALL PLOT(0 ,0 ,5)
509   RETURN
      END

C*********************************************************************
C
C      SUBROUTINE ATMOS PRINTS ALL UNREDUCED GROUND ATMOSPHERIC DATA,
C CORRECTS IT FOR PSYCHROMETER AND BAROMETER OFFSETS AND REDUCES IT
C TO REDUCED REFRACTIVE INDICES  THE MEAN PRESSURE, TEMPERATURE,
C WATER VAPOR PRESSURE, AND REDUCED REFRACTIVE INDEX ARE RETURNED
C
C                            PARAMETER LIST
C    ID    SECTION IDENTIFICATION (BA OR RE)
C    BARC  BAROMETER CORRECTION (MBAR)
C    Y     PSYCHROMETER CORRECTIONS (2X2 ARRAY CONTAINING THE SLOPE
C          AND INTERCEPTS FOR EACH THERMOMETER)
```

```
C    PRE    MEAN PRESSURE FOR THE STATION (RETURNED)
C    TEM    MEAN TEMPERATURE FOR THE STATION (RETURNED)
C    HUM    MEAN WATER VAPOR PRESSURE FOR THE STATION (RETURNED)
C    A5     MEAN REDUCED REFRACTIVE INDEX FOR THE STATION (RETURNED)
C    LOC    ARRAY CONTAINING THE LOCATION OF THE STATION
C
C**********************************************************************

      SUBROUTINE ATMOS(ID,BARC,Y,PRE,TEM,HUM,A5,LOC)
      COMMON /LASER/BR,BA,RE,HC,HA,GO,HR,MN,SEC,DEBUG,NUM,
     2DA,MO,YR,H2,NTITLE,IPLOT(17),IR,NMO(200)
      INTEGER DA(200),MO(200),YR(200),H2(80),TIC(7),LOC(4)
      INTEGER TTL(18),TTH(5),TTG(6),TTF(7),TTA(5),TTB(5),TTD(5),TTE(6)
      REAL TWET(200),TDRY(200),PRESS(200),REF(200),Y(2,2)
      INTEGER BR,BA,RE,HC,HA,GO,DEBUG,STAR
      INTEGER H(9,200),HR(200),MN(200),SEC(200),MARK(200)
      DATA III/'  '/,RE/'RE'/,STAR/'*'/
      DATA TTH/' + ','GRA','PH ','VAL','UE'/
      DATA TTG/'MB ','+ G','RAP','H V','ALU','E  '/
      DATA TTF/'DEG','  C',' + ','GRA','PH ','VAL','UE '/
      DATA TTA/'WET',' TE','MPE','RAT','URE'/
      DATA TTB/'DRY',' TE','MPE','RAT','URE'/
      DATA TTD/'VAP','OR ','PRE','SSU','RE '/
      DATA TTE/'REF','RAC','TIV','E N','UMB','ER '/
      DATA TTC/'BAR','OME','TRI','C P','RES','SUR','E  '/
      DO 971 I=1,18
971   TTL(I)=III
      N1=1
      K=0
      A5=0
      TEM=0
      PRE=0
      HUM=0
      N=6
      IF(ID EQ RE) N=12
      WRITE(6,10)
 10   FORMAT('0','UNCORRECTED DATA',//,
     13X,'TIME     WET     DRY    BAROMETRIC  COMMENTS',/,
     2' HR MN SEC TEMP    TEMP    PRES(MB)',/)
C
C READS & WRITES UNCORRECTED DATA
C
 30   READ(25,15) IP,HR(N1),MN(N1),SEC(N1),TWET(N1),TDRY(N1),PRESS(N1),
     2MARK(N1),(H(I,N1),I=1,9)
 15   FORMAT(A2,1X,3I2,1X,2(F3 1,1X),F6 2,A1,9A3)
      IF(IP NE.ID) GO TO 35
      N=N+1
      IF(N LT 56) GO TO 31
      NUM=NUM+1
      WRITE (6,40) (H2(I),I=1,18),NUM
 40   FORMAT('1',18A3,13X,'PAGE#',I2)
      WRITE(6,10)
      N=0
 31   WRITE(6,20)HR(N1),MN(N1),SEC(N1),TWET(N1),TDRY(N1),PRESS(N1),
     2MARK(N1),(H(I,N1),I=1,9)
 20   FORMAT(3(1X,I2),2X,2(F4 1,3X),F7 2,A1,3X,9A3)
      N1=N1+1
      GO TO 30
 35   N1=N1-1
C
C INTERPOLATES DATA
C
      CALL INTERP(N1)
      TSCA=3600*HR(N1)+60*MN(N1)-3600*HR(1)-60*MN(1)
```

```
      IF(TSCA LT 0) TSCA=TSCA+86400
      TSCA=.19685/(AINT(TSCA/60))
      CALL  NTERP2(TWET,N1)
      CALL  NTERP2(TDRY,N1)
      CALL  NTERP2(PRESS,N1)
      IF(IPLOT(2) NE 1) GO TO 666
       CALL MPLOT(N1,TWET,TWET,TTL,1,TTA,15,TTF,20,TSCA,0 7874,1,
     3 MARK,1,LOC,TTL,3)
      CALL PLOT(0 ,0 ,5)
 666  IF(IPLOT(3) NE 1) GO TO 667
       CALL MPLOT(N1,TWET,TDRY,TTL,1,TTB,15,TTF,20,TSCA,0 7874,1,
     3 MARK,1,LOC,TTL,3)
      CALL PLOT(0 ,0 ,5)
 667  IF(IPLOT(4) NE 1) GO TO 668
       CALL MPLOT(N1,TWET,PRESS,TTL,1,TTC,19,TTG,16,TSCA,3 937,1,
     3 MARK,2,LOC,TTL,3)
      CALL PLOT(0.,0 ,5)
 668  IF (DEBUG.EQ 999) GO TO 85
      IF(N LE 44) GO TO 36
      NUM=NUM+1
      WRITE (6,40) (H2(I),I=1,18),NUM
      N=-6
 36   WRITE(6,55)
      N=N+6
      DO 50 I=1,N1
C
C CHECKS FOR DATA TO BE USED
C
      IF (MARK(I) EQ STAR) DEBUG=99
      IF (DEBUG NE 99) GO TO 50
      K=K+1
      YR(K)=YR(I)
      MO(K)=MO(I)
      DA(K)=DA(I)
      HR(K)=HR(I)
      MN(K)=MN(I)
      SEC(K)=SEC(I)
C
C THERMOMETER & BAROMETER CORRECTION
C
      TWET(I)=Y(1,1)+Y(2,1)*TWET(I)
      TDRY(K)=Y(1,2)+Y(2,2)*TDRY(I)
      TEM=TEM+TDRY(K)
  65  PRESS(K)=PRESS(I)+BARC
      PRE=PRE+PRESS(K)
C
C CALCULATES WATER VAPOR PRESSURE E
C
  70  TWET(K)=269782133*EXP(-4271 071252/(TWET(I)+242 625445))
     2- 00066*(1 + 00115*TWET(I))*PRESS(K)*(TDRY(K)-TWET(I))
      HUM=HUM+TWET(K)
C
C CALCULATES REFRACTIVE NUMBER
C
  75  REF(K)=(300 2*PRESS(K)-41 8*TWET(K))/(3 709*(TDRY(K)+273 15))
      A5=A5+REF(K)
      N=N+1
      IF(N LT 56) GO TO 51
      NUM=NUM+1
      WRITE (6,40) (H2(J),J=1,18),NUM
      N=0
      WRITE(6,55)
C
C WRITES CORRECTED DATA AND MEANS
```

```
C
 51    WRITE(6,60) HR(K),MN(K),SEC(K),TDRY(K),PRESS(K),TWET(K),REF(K),
     2(H(J,I),J=1,9)
       IF (MARK(I).EQ.STAR.AND.K.GT.1) DEBUG=0
       MARK(K)=0
  50   CONTINUE
  60   FORMAT(3(1X,I2),2X,F4.1,3X,F7.2,3X,F5.2,2X,F5.1,2X,9A3)
       TSCA=3600*HR(K)+60*MN(K)-3600*HR(1)-60*MN(1)
       IF(TSCA.LT.0) TSCA=TSCA+86400
       TSCA= 19685/(AINT(TSCA/60))
       IF(IPLOT(9).NE.1)  GO TO 669
        CALL MPLOT( K,TWET,TDRY,TTL,1,TTB,15,TTF,20,TSCA,0.7874,1,
     3 MARK,1,LOC,TTL,2)
       CALL PLOT(0.,0.,5)
 669   IF(IPLOT(10).NE.1)  GO TO 670
        CALL MPLOT( K,TWET,PRESS,TTL,1,TTC,19,TTG,16,TSCA,3.937,1,
     3 MARK,2,LOC,TTL,4)
       CALL PLOT(0.,0.,5)
 670   IF(IPLOT(11).NE.1) GO TO 671
        CALL MPLOT( K,TWET,TWET,TTL,1,TTD,14,TTG,16,TSCA,0.9685,1,
     3 MARK,2,LOC,TTL,4)
       CALL PLOT(0.,0.,5)
 671   IF(IPLOT(12).NE.1) GO TO 672
        CALL MPLOT(K,TDRY,REF,TTL,1,TTE,17,TTH,14,TSCA,0.9685,1,MARK,
     2 1,LOC,TTL,1)
       CALL PLOT (0.,0.,5)
  55   FORMAT('0', 'REDUCED ATMOSPHERIC DATA',//,
     2'    TIME     DRY    BAROMETRIC    E       N     COMMENTS',/,
     3' HR MN SEC TEMP    PRES(MB)',/)
 672   TEM=TEM/K
       PRE=PRE/K
       HUM=HUM/K
       A5=A5/K
       WRITE(6,80) TEM,PRE,HUM,A5
  80   FORMAT('0','MEANS',5X,F4.1,3X,F7.2,3X,F5.2,2X,F5.1)
  85   ID=IP
       IFLAG=0
       RETURN
       END

C**********************************************************************
C
C SUBROUTINE CALIBR PRINTS AND REDUCES HELICOPTER CALIBRATION DATA.
C
C                                   PARAMETER LIST
C    ID              SECTION IDENTIFICATION (HC)
C    P               PSYCHROMETER CORRECTIONS (2X2 ARRAY CONTAINING SLOPE
C                    AND INTERCEPT FOR BOTH THERMOMETERS)
C    CALIB,D,E,F     CONSTANTS FOR CONVERTING HYGRISTOR RESISTANCE TO WATER
C                    VAPOR PRESSURE
C    A,B,C,R25       CONSTANTS FOR COMPUTING TEMPERATURE FROM THERMISTOR
C                    RESISTANCE
C    C,T,S           CONSTANTS FOR CALCULATING PRESSURE FROM TRANSDUCER
C                    FREQUENCY
C
C**********************************************************************

        SUBROUTINE CALIBR(ID,P,CALIB,A,B,C,R25,D,F,E,G,T,S)
        COMMON /TASER/BR,BA,RE,HC,HA,CO,HR,MN,SEC,DEBUG,NUM,
      2DA,MO,YR,H2,NTITLE,IPLOT(17),IR,NMO(200)
        INTEGER DA(200),YR(200),MO(200),LOC(4),H(3),PSY,BAR,OB(5),
      2HR(200),MN(200),SEC(200)
        INTEGER BR,BA,RE,HC,HA,CO,DEBUG,H2(80)
        REAL TWET(50),TDRY(50),RTH(50),RHYG(50),PRESS(50),FREQ(50),
```

```
     2P(2,2,6)
C
C READS & WRITES HEADER
C
      READ(25,50) DA(1),MO(1),YR(1),(LOC(J),J=1,4),(H(K),K=1,3),PSY,BAR,
     2BARC,CALIB,S,(OB(I),I=1,5)
 50   FORMAT(3X,3I2,1X,4A3,1X,3A3,2(I1,1X),F4 1,1X,F4 2,1X,F7 2,1X,5A3)
      NUM=NUM+1
      WRITE (6,40) (H2(I),I=1,18),NUM
 40   FORMAT('1',18A3,13X,'PAGE#',I2)
      WRITE(6,10) (H(K),K=1,3),(LOC(J),J=1,4),PSY,
     2BAR,BARC,CALIB,S,(OB(I),I=1,5)
 10   FORMAT('0',   3A3,'CALIBRATION OF THE HELICOPTER HYGRISTOR AT ',
     24A3,/,' PSYCHROMETER #',I1,3X,' BAROMETER #',
     3I1,/,' BAROMETER CORRECTION. ',F5 2,' MBAR',/,
     4 ' CALIBRATION RESISTANCE OF THE HYGRISTOR  ',
     ^ F5 1,' KOHM',/,' ZERO PRESSURE FREQUENCY OF DIGIQUARTZ  ',
     2F8 2,' HZ',/,' OBSERVER  ',5A3,//,' UNCORRECTED ',
     4'DATA',//,2X,' TIME     WET     DRY     THERM    ',
     5'HYGRIS BAROMETRIC  DIGIQTZ  COMMENTS',/,' HR MN SEC TEMP    TEMP
     6 (KOHM)  (KOHM)  PRES(MB)  FREQ (HZ)',/)
      N1=1
C
C READS & WRITES UNCORRECTED DATA
C
 30   READ(25,15) ID,HR(N1),MN(N1),SEC(N1),TWET(N1),TDRY(N1),PRESS(N1),
     2RTH(N1),FREQ(N1),RHYG(N1),(LOC(I),I=1,4)
      IF(ID NE HC)GO TO 35
 15   FORMAT(A2,1X,3I2,2(1X,F3 1),1X,F6 2,1X,F4 2,1X,F6 1,1X,F5 1,1X,
     24A3)
      WRITE(6,20) HR(N1),MN(N1),SEC(N1),TWET(N1),TDRY(N1),RTH(N1),
     2RHYG(N1),PRESS(N1),FREQ(N1),(LOC(I),I=1,4)
      N1=N1+1
 20   FORMAT(3(1X,I2),2X,2(F4 1,3X),F5 2,3X,F6 1,2X,F7 2,4X,F7 1,2X,4A3)
      GO TO 30
 35   N1=N1-1
      IF (DEBUG EQ 999) RETURN
      WRITE(6,60)
  60  FORMAT('0','REDUCED DATA',//,
     1'   TIME    DIGITAL DIGIQTZ  DRY  THER    E     E',
     2/,' HR MN SEC  PRESS    PRESS    TEMP TEMP  GRND  HELI ',/)
      CALL INTERP(N1)
      CALL NTERP2(TWET,N1)
      CALL NTERP2(TDRY,N1)
      CALL NTERP2(RTH,N1)
      CALL NTERP2(RHYG,N1)
      CALL NTERP2(PRESS,N1)
      CALL NTERP2(FREQ,N1)
      DO 65 I=1,N1
C
C BAROMETER & PSYCHROMETER CORRECTIONS
C
      PRESS(I)=PRESS(I)+BARC
      TWET(I)=P(1,1,PSY)+P(2,1,PSY)*TWET(I)
      TDRY(I)=P(1,2,PSY)+P(2,2,PSY)*TDRY(I)
C
C CALCULATES WATER VAPOR PRESSURE E
C
      TWET(I)=7 04623+ 1958316 1*TWET(I)+ 031358*(TWET(I)**2)-.00066*(1+
     2 00115*TWET(I))*PRESS(I)*(TDRY(I)-TWET(I))
C
C CONVERTS THERMISTOR RESISTANCE TO TEMPERATURE
C
      RTH(I)=ALOG(RTH(I)/R25)
```

```
      RTH(I)=1/(A+B*RTH(I)+C*RTH(I)**3)-273 15
C
C CALCULATES PRESSURE FROM DIGIQUARTZ FREQUENCY
C
      FREQ(I)=G*(1-FREQ(I)/S)-T*(1-FREQ(I)/S)**2
C
C COMPUTES E FROM HYGRISTOR RESISTANCE
C
      RHYG(I)=RHYG(I)/CALIB
      RHYG(I)=RHYG(I)*(1-( 01401+ 36991*ALOG10(RHYG(I))- 11159
     2*(ALOG10(RHYG(I)))**2)*(1-RTH(I)/25 ))
      RHYG(I)=ALOG10(RHYG(I))
      RHYG(I)=(D+E*RHYG(I)+F*(RHYG(I))**2)*(269782133*
     2EXP(-4271 071252/(RTH(I)+242 625445)))/100
C
C WRITES REDUCED DATA
C
      WRITE(6,70) HR(I),MN(I),SEC(I),PRESS(I),FREQ(I),TDRY(I),RTH(I),
     2TWET(I),RHYG(I)
   70 FORMAT(3(1X,I2),2X,F7 2,1X,F7 2,2X,2(F4 1,1X),2(1X,F5 2))
   65 CONTINUE
      RETURN
      END

C*******************************************************************
C
C       H ATM PRINTS AND REDUCES THE HELICOPTER ATMOSPHERIC DATA TO
C PRESSURE, TEMPERATURE, WATER VAPOR PRESSURE, AND REDUCED REFRACTIVE
C INDEX  GROUND DATA ARE INSERTED AS ENDPOINTS TO THE LINE  ALTITUDES,
C REDUCED REFRACTIVE INDICES, AND THE NUMBER OF POINTS ARE RETURNED
C TO THE MAIN PROGRAM
C
C                                 PARAMETER LIST
C   ID             SECTION IDENTIFICATION (HA)
C   CALIB,D,E,F CONSTANTS FOR CONVERTING HYGRISTOR RESISTANCE TO WATER
C                  VAPOR PRESSURE
C   A,B,C,R25      CONSTANTS FOR COMPUTING TEMPERATURE FROM THERMISTOR
C                  RESISTANCE
C   G,T,P,Q,R      CONSTANTS FOR CALCULATING PRESSURE FROM TRANSDUCER
C                  FREQUENCY
C   ELE            ENDPOINT ELEVATIONS
C   PRE            MEAN PRESSURES AT ENDPOINTS
C   TEM            MEAN TEMPERATURES AT ENDPOINTS
C   HUM            MEAN WATER VAPOR PRESSURES AT ENDPOINTS
C   ALT            HELICOPTER ALTITUDES (RETURNED)
C   REF            REDUCED REFRACTIVE INDICES (RETURNED)
C   K              TOTAL NUMBER OF REDUCED DATA POINTS ALONG THE LINE
C                  (RETURNED)
C   LOC            ARRAY CONTAINING THE LOCATION OF THE STATION THAT
C                  THE HELICOPTER IS FLYING FROM
C   OB             ARRAY CONTAINING THE LOCATION OF THE STATION THAT
C                  THE HELICOPTER IS FLYING TO
C
C*******************************************************************

      SUBROUTINE H ATM(ID,CALIB,A,B,C,R25,D,E,F,G,T,P,Q,R,ELE,PRE,TEM,
     2HUM,ALT,REF,K,LOC,OB)
      COMMON/LASER/ BR,BA,RE,HC,HA,CO,HR,MN,SEC,DEBUG,NUM,
     2DA,MO,YR,H2,NTITLE,IPLOT(17),IR,NMO(200)
      INTEGER TTE(6),TTD(5),TTC(10),TTX(5),TTF(7),LOC(4),OB(4)
      INTEGER TTT(4),TTI(6),TTA(7),TTB(9),TTL(18),TTJ(1),TTG(6)
      INTEGER DA(200),MO(200),YR(200),H2(80),TTK(5),TTZ(6)
      INTEGER BR,BA,RE,HC,HA,CO,DEBUG,STAR
      INTEGER H(9,200),HR(200),MN(200),SEC(200),MARK(200)
```

```
      REAL RTH(200),FREQ(200),RHYG(200),REF(200), RLI(200),TEM(2),
     2PRE(2),ELE(2),HUM(2),AIRSP(200),ALT(200)
      DATA TTE/'(N ','- L','INE','AR ','TER','M) '/
      DATA TTD/'VAP','OR ','PRE','SSU','RE '/
      DATA TTC/'THE','RMI','STO','R R','ESI','STA','NCE',' (K',
     2'OHM',')  '/
      DATA TTX/'ALT','ITU','DE ','(KM',')  '/
      DATA TTF/'DEG','  C',' + ','GRA','PH ','VAL','UE '/
      DATA TTG/'KM ','+ G','RAP','H V','ALU','E  '/
      DATA TTT/'TEM','PER','ATU','RE '/
      DATA TTI/'HZ ','+ G','RAP','H V','ALU','E  '/
      DATA TTA/'DIG','IQU','ART','Z F','REQ','UEN','CY '/
      DATA TTB/'HYG','RIS','TOR',' RE','SIS','TAN','CE ','(KO',
     2'HM)'/
      DATA TTK/' + ','GRA','PH ','VAL','UE '/
      DATA TTZ/'MB ','+ G','RAP','H V','ALU','E  '/
      DATA III/' '/,STAR/'*'/
      DATA TTJ/' '/
      DO 971 I=1,18
971   TTL(I)=III
      N1=1
      N=2
      WRITE(6,10)
 10   FORMAT('0','UNCORRECTED DATA',//,
     1             '   TIME      ALT    VEL  THERM    DIGIQTZ  HYGRIS  ',
     2'COMMENTS',/,' HR MN SEC  (KM)   MPH    KOHM    FREQ (HZ)   KOHM',/)
C
C READS & WRITES UNCORRECTED DATA
C
 30   READ(25,15) IP,HR(N1),MN(N1),SEC(N1),ALT(N1),AIRSP(N1),RTH(N1),
     2FREQ(N1),RHYG(N1),MARK(N1),(H(I,N1),I=1,9)
      ALT(N1)=ALT(N1)* 3048E-03
 15   FORMAT(A2,1X,3I2,1X,F5 0,1X,F3 0,1X,F4.2,1X,F6 1,1X,F5 1,A1,9A3)
      IF(IP NE ID) GO TO 35
      N=N+1
      IF(N LT 56) GO TO 31
      NUM=NUM+1
      WRITE (6,40) (H2(J),J=1,18),NUM
 40   FORMAT('1',18A3,13X,'PAGE#',I2)
      N=0
      WRITE(6,10)
 31   WRITE(6,20) HR(N1),MN(N1),SEC(N1),ALT(N1),AIRSP(N1),RTH(N1),
     2FREQ(N1),RHYG(N1),MARK(N1),(H(I,N1),I=1,9)
 20   FORMAT(3(1X,I2),2X,F5 3,2X,F4 0,2X,F5 2,3X,F7 1,2X,F6 1,A1,1X,9A3)
      N1=N1+1
      GO TO 30
 35   N1=N1-1
C
C INTERPOLATES DATA
C
      CALL  INTERP(N1)
      TSCA=3600*HR(N1)+60*MN(N1)-3600*HR(1)-60*MN(1)
      IF(TSCA LT 0) TSCA=TSCA+86400
      TSCA= 19685/(AINT(TSCA/60))
      CALL  NTERP2(AIRSP,N1)
      CALL NTERP2(FREQ,N1)
      CALL NTERP2(RHYG,N1)
      CALL NTERP2(RTH,N1)
      IF(IPLOT(6) NE 1) GO TO 603
       CALL MPLOT(N1,RTH,RTH,TTL, 1,TTC,28,TTK,14,TSCA, 3937,1,MARK,2
     3,IOC,OB,3)
      CALL PLOT(0 ,0 ,5)
 603  IF(IPLOT(7) NE 1) GO TO 604
       CALL MPLOT(N1,RTH,RHYG,TTL, 1,TTB,27,TTK,14,TSCA, 0019685,1,
```

```
      3 MARK,1,LOC,OB,3)
       CALL PLOT(0 ,0 ,5)
 604   IF(IPLOT(5) NE .1) GO TO 602
        CALL MPLOT(N1,RTH,FREQ,TTL,1,TTA,20,TTI,16,TSCA, 003937,1,
      3 MARK,1,LOC,OB,2)
       CALL PLOT(0.,0 ,5)
  602  IF (DEBUG EQ 999) GO TO 85
       IF(N LE 49) GO TO 36
       NUM=NUM+1
       WRITE (6,40) (H2(J),J=1,18),NUM
       N=-6
  36   WRITE(6,60)
       N=N+6
C
C PUTS GROUND DATA IN THE SAME ORDER AS THE HELICOPTER DATA
C
       REF1=REF(1)
       REF2=REF(2)
       AM=FREQ(1)-FREQ(N1)
       IF(AM GE 0 ) GO TO 70
       EM=ELE(1)
       ELE(1)=ELE(2)
       ELE(2)=EM
       EM=REF1
       REF1=REF2
       REF2=EM
       EM=TEM(1)
       TEM(1)=TEM(2)
       TEM(2)=EM
       EM=HUM(1)
       HUM(1)=HUM(2)
       HUM(2)=EM
       EM=PRE(1)
       PRE(1)=PRE(2)
       PRE(2)=EM
  70   PRES=PRE(1)
       TEMP=TEM(1)
       HUMI=HUM(1)
       ALTI=ELE(1)
       K=0
       DO 50 I=1,N1
C
C CHECKS FOR DATA TO BE USED
C
       IF (MARK(I) EQ STAR) DEBUG=99
       IF (DEBUG NE 99) GO TO 50
       K=K+1
       YR(K)=YR(I)
       MO(K)=MO(I)
       DA(K)=DA(I)
       HR(K)=HR(I)
       MN(K)=MN(I)
       SEC(K)=SEC(I)
       DO 80 J=1,9
  80   H(J,K)=H(J,I)
C
C CONVERTS THERMISTOR RESISTANCE TO TEMPERATURE
C
       RTH(I)=ALOG(RTH(I)/R25)
       RTH(K)=1 /(A+B*RTH(I)+C*(RTH(I)**3))-273 15
C
C COMPUTES E FROM HYGRISTOR RESISTANCE
C
       RHYC(I)=RHYC(I)/CALIB
```

```
      RHYG(I)=RHYG(I)*(1-(.36991*ALOG10(RHYG(I))+.01401-.11159
     2*(ALOG10(RHYG(I)))**2)*(1 -RTH(K)/25 ))
      RHYG(I)=ALOG10(RHYG(I))
      RHYG(I)=(D+E*RHYG(I)+F*(RHYG(I)**2))/100
      RHYG(K)=RHYG(I)*269782133*EXP(-4271 071252/(RTH(K)+242 625445))
      IF(RHYG(K) LT 0 ) RHYG(K)=0
C
C CALCULATES PRESSURE FROM DIGIQUARTZ FREQUENCY
C
      FREQ(I)=G*(1 -FREQ(I)/P)-T*(1-FREQ(I)/P)**2
      FREQ(K)=FREQ(I)*(1 -Q*AIRSP(I)+R/1012 *AIRSP(I)**2)
C
C CALCULATES HELICOPTER ALTITUDES
C
      ALT(K) =18 400*ALOG10(PRES  /FREQ(K))*(1 + 00367*((TEMP
     2+RTH(K))/2 ))*(1 + 378*((HUMI  /PRES  +RHYG(K)/FREQ(K))/2.))*
     3 1 001958*(1 +2 *ALTI/6371 )+ALTI
      PRES=FREQ(K)
      TEMP=RTH(K)
      HUMI=RHYG(K)
      ALTI=ALT(K)
C
C CALCULATES REFRACTIVE NUMBER
C
      REF(K)=(300 2*FREQ(K)-41 8*RHYG(K))/(3 709*(RTH(K)+273 15))
      IF (MARK(I) EQ STAR AND.K GT 1) DEBUG=0
      MARK(K)=0
 50   CONTINUE
      ALTI=18 4*ALOG10(PRES/PRE(2))*(1 + 00367*((TEMP+TEM(2))/2 ))*
     2 (1 + 378*((HUMI/PRES+HUM(2)/PRE(2))/2 ))*1 001958*(1 +(ALTI+
     3 ELE(2))/6371 0)+ALT(K)
      AM=ALTI-ELE(2)
C
C CALCULATES HUMPHREYS MULTIPLICATION CONSTANT & CORRECTS ALTITUDES
C
      DIFF=(ELE(2)-ELE(1))/(ALTI-ELE(1))
      DO 55 I=1,K
      ALT(I)=ALT(I)-AM*(1 -(ALT(I)-ALTI)/(ELE(1)-ALTI))
      N=N+1
      IF (N LE 54) GO TO 51
      NUM=NUM+1
      N=0
      WRITE (6,40) (H2(J),J=1,18),NUM
      WRITE(6,60)
 60   FORMAT('0',    'REDUCED HELICOPTER ATMOSPHERIC DATA',//,
     2'    TIME    ADJUSTED  PRESS    TEMP     L        N      COMMENTS',/,
     3' HR MN SEC ALT (KM)     (MB)',/)
C
C WRITES DATA
C
 51   WRITE(6,65) HR(I),MN(I),SEC(I),ALT(I),FREQ(I),
     2RTH(I),RHYG(I),REF(I),(H(J,I),J=1,9)
 65   FORMAT(3(1X,I2),2X,F7 5,2X,F7.2,2X,F4 1,2X,F5 2,2X,F5.1,2X,
     29A3)
 55   CONTINUE
      SCA=20 /(ABS(ALT(1)-ALT(K)))/2 54
      WRITE(6,37) DIFF
 37   FORMAT('0','MULTIPLICATION CONSTANT TO HUMPHREYS FORMULA= ',F8.6)
      TSCA=3600*HR(N1)+60*MN(N1)-3600*HR(1)-60*MN(1)
      IF(TSCA LT 0) TSCA=TSCA+86400
      TSCA= 19685/(AINT(TSCA/60))
      IF(IPLOT(16) NE 1) GO TO 606
       CALL MPLOT(K,ALT,REF,FTI ,1,TTE,23,TTG,14,TSCA,.03937,1,MARK,1
     1,LOC,OB,1)
```

```
      CALL PLOT(0.,0.,5)
C
C INSERTS GROUND DATA INTO HELICOPTER LINE
C
 606  DO 75 I=1,K
      L=K+1-I
      M=L+1
      ALT(M)=ALT(L)
      REF(M)=REF(L)
      RTH(M)=RTH(L)
      MARK(M)=0
  75  RHYG(M)=RHYG(L)
      ALT(1)=ELE(1)
      REF(1)=REF1
      RTH(1)=TEM(1)
      RHYG(1)=HUM(1)
      K=K+2
      ALT(K)=ELE(2)
      REF(K)=REF2
      RTH(K)=TEM(2)
      MARK(K)=0
      RHYG(K)=HUM(2)
      IF (ALT(1) LT ALT(K)) GO TO 56
      DO 57 I=1,4
      J=OB(I)
      OB(I)=LOC(I)
57    LOC(I)=J
56    DO 54 I=1,K
C
C COMPUTES REFRACTIVE NUMBER MINUS LINEAR TERM
C
 54   REI(I)=REF(I)+(REF(1)-REF(K))/(ALT(K)-ALT(1))*ALT(I)-
     2 (ALT(K)+ALT(1))*(REF(1)-REF(K))/(2 *(ALT(K)-ALT(1)))
      SCA=20 /(ABS(ALT(K)-ALT(1)))/2.54
      IF(IPLOT(13) NE 1) GO TO 607
       CALL MPLOT(K,ALT,RTH,TTX,13,TTT,11,TTF,20,SCA, 19685,0,MARK,2,
     1LOC,OB,2)
      CALL PLOT(0 ,0 ,5)
 607  IF(IPLOT(14) NE 1) GO TO 608
       CALL MPLOT(K,ALT,RHYG,TTX,13,TTD,14,TTZ,16,SCA, 15748,0,MARK,2,
     1LOC,OB,4)
      CALL PLOT(0 ,0 ,5)
608   IF(IPLOT(15) NE 1) GO TO 85
      CALL MPLOT(K,ALT,REI,TTX,13,TTE,17,TTK,14,SCA, 3937,0,MARK,2,
     1LOC,OB,1)
      CALL PLOT(0 ,0 ,5)
  85  ID=IP
      RETURN
      END
C
C SUBROUTINE INTERP INTERPOLATES TIME
C
      SUBROUTINE INTERP(N1)
      COMMON /LASER/BR,BA,RE,HC,HA,GO,HR,MN,SEC,DEBUG,NUM,
     2DA,MO,YR,H2,NTITLE,IPLOT(17),IR,NMO(200)
      INTEGER BR,BA,RE,HC,HA,GO,DEBUG
      INTEGER DA(200),MO(200),YR(200),H2(80)
      INTEGER TIME(200),HR(200),MN(200),SEC(200)
      N=0
      DO 50 I=1,N1
      TIME(I)=HR(I)*3600+MN(I)*60+SEC(I)
      IF(TIME(I) NE 0) GO TO 55
      N=N+1
      GO TO 50
```

```
   55 IF(N EQ 0) GO TO 50
      J=I-N-1
      J1=TIME(I)-TIME(J)
      IF(J1 LE -9000) TIME(I)=TIME(I)+86400
      J1=(TIME(I)-TIME(J))/(N+1)
      L=J+N
      J=J+1
      DO 60 K=J,L
      K1=K-1
      TIME(K)=TIME(K1)+J1
      HR(K)=TIME(K)/3600
      MN(K)=(TIME(K)-HR(K)*3600)/60
      SEC(K)=TIME(K)-HR(K)*3600-MN(K)*60
      IF(HR(K) LT 24) GO TO 60
      HR(K)=HR(K)-24
      TIME(K)=TIME(K)-86400
   60 CONTINUE
      N=0
   50 CONTINUE
      JDA=DA(1)
      DO 40 I=1,N1
      J1=I-1
      IF(J1 NE 0 AND.HR(J1).GT HR(I)) JDA=JDA+1
      YR(I)=YR(1)
      MO(I)=MO(1)
      DA(I)=JDA
   40 CONTINUE
      RETURN
      END
C
C SUBROUTINE NTERP2 INTERPOLATES ANY SINGLE ARRAY
C
      SUBROUTINE  NTERP2(DATA,N1)
      REAL J1,DATA(200)
      N=0
      DO 45 M=1,N1
45    IF(DATA(M) NE 0 ) GO TO 40
   40 DO 50 I=M,N1
      IF(DATA(I) NE 0) GO TO 55
      N=N+1
      GO TO 50
   55 IF(N EQ 0) GO TO 50
      J=I-N-1
      J1=(DATA(I)-DATA(J))/(N+1)
      L=J+N
      J=J+1
      DO 60 K=J,L
      K1=K-1
      DATA(K)=DATA(K1)+J1
   60 CONTINUE
      N=0
   50 CONTINUE
      RETURN
      END
      SUBROUTINE MPLOT (NAR,XD,YP,IXTITL,NXTITL,IYTITL,NYTITL,IZTITL,
     1NZTITL,XSCALE,YSCALE,IT,ICH,IDFLAG,LOC1,LOC2,ISTHD)
C **********************************************************************
C *                                                                    *
C *                                                                    *
C *       THIS SUBPROGRAM IS A PLOTTING ROUTINE WRITTEN BY J E WOLFE   *
C * SUMMER, 1977   MAKING USE OF SUBROUTINES GNPLOT, AAXS, AND TAXIS,  *
C * IT PLOTS EITHER TIME OR DECIMAL DATA ON THE X-AXIS AND CAN ANNOTATE*
C * THE X-AXIS DOWN TO 10 MINUTE INTERVALS AND UP TO ONLY MONTHS   THE *
C * DECIMAL ANNOTATION OF EITHER AXIS IS MADE TO BE EVEN NUMBERS AND   *
```

```
C * ONLY THE SIGNIFICANT PART IS WRITTEN   Y-AXIS TAKES ONLY DECIMAL   *
C * VALUES, IT DOES NOT TAKE TIME DATA                                 *
C *                                                                    *
C *     EXPLANATION OF PARAMETERS PASSED TO SUBROUTINE MPLOT IN THE    *
C *     SUBROUTINE STATEMENT                                           *
C * NAR - NUMBER OF POINTS TO BE PLOTTED                               *
C * XD - X-AXIS VALUES (DECIMAL), IF TIME PLOT MAKE XD DUMMY ARRAY     *
C * YP - Y-AXIS VALUES (DECIMAL)                                       *
C * IXTITL - X-AXIS EXPLANATION (INCLUDING DIMENSIONS).                *
C * NXTITL - NUMBER OF LETTERS IN IXTITL                               *
C * IYTITL - Y-AXIS EXPLANATION                                        *
C * NYTITL - NUMBER OF LETTERS IN IYTITL                               *
C * IZTITL - CONTAINS THE DIMENSIONS OF THE Y-AXIS VALUES AND THE      *
C *          PHRASE  ' + GRAPH VALUES'                                 *
C * NZTITL - NUMBER OF LETTERS IN IZTITL.                              *
C * XSCALE - SCALING FACTOR FOR X-AXIS IN INCHES/UNITS                 *
C * YSCALE - SCALING FACTOR FOR Y-AXIS IN INCHES/UNITS                 *
C * IT - INDICATOR FOR TIME OR DECIMAL PLOTS,IF IT=0, DECIMAL PLOT     *
C *      IF IT=1, TIME PLOT                                            *
C * ICH - ARRAY CORRESSPONDING TO XD ARRAY, FOR MARKING TWO POINTS     *
C *       ALONG THE X-AXIS OF SPECIAL SIGNIFICANCE, EXAMPLE, BEGINNING *
C *       AND ENDING TIME OF HELICOPTER FLYING LINE                    *
C * IDFLAG - NUMBER OF SIGNIFICANT FIGURES TO THE RIGHT OF THE DECIMAL *
C *          PLACE FOR Y-AXIS VALUES                                   *
C * LOC1 - THE LOCATION AT WHICH DATA IS TAKEN   WHERE THE X-AXIS IS   *
C *        DISTANCE, IT IS THE LOCATION AT BEGINNING OF PLOT           *
C * LOC2 - WHERE Y-AXIS IS DISTANCE, THIS IS THE LOCATION AT END OF    *
C *        PLOT   NOTE  IF NO LOCATIONS DESIRED PRINTED ON PLOT, PASS  *
C *        BLANK ARRAYS IN LOC1 AND LOC2                               *
C * ISTHD - INDICATOR FOR WHAT EXPLANATIONS TO WRITE OUT, USED IN      *
C *         STACKING VARIOUS PLOTS OF ONE COMMON X-AXIS VARIABLE       *
C *         IF.                                                        *
C *            ISTHD=1 WRITES ONLY THE TITLE OF PLOT (ARRAY ITITLE)    *
C *            ISTHD=2 WRITES ONLY THE X-AXIS EXPLANATION              *
C *            ISTHD=3 WRITES BOTH THE TITLE AND THE X-AXIS EXPLANATION*
C *         ELSE  WRITES NEITHER THE TITLE NOR THE X-AXIS EXPLANATION  *
C *                                                                    *
C *                                                                    *
C *     EXPLANATION OF PARAMETERS REQUIRED BY SUBROUTINE MPLOT PASSED  *
C *      IN COMMON AREA LASER.                                         *
C *                                                                    *
C * NHOUR - ARRAY OF THE HOURS OF EACH POINT IN Z-HOURS                *
C * NMIN - ARRAY OF THE MINUTES OF EACH POINT IN Z-HOURS               *
C * NSEC - ARRAY OF THE SECONDS OF EACH POINT IN Z-HOURS               *
C * NDAY - ARRAY OF THE DAY OF THE MONTH OF EACH POINT IN NUMBER FORM  *
C * MO - ARRAY OF THE MONTH OF THE YEAR OF EACH POINT IN NUMBER FORM   *
C * NYR - ARRAY OF THE LAST TWO DIGITS OF THE YEAR OF EACH POINT       *
C * ITITLE - THE TITLE OF THE PLOT                                     *
C * NTITLE - NUMBER OF LETTERS IN ITITLE                               *
C *                                                                    *
C *                                                                    *
C **********************************************************************
      COMMON/TAX/ NHRMIN(200),HR(200),DAY(200),YEAR(200),SECSUB(200)
      COMMON/LASER/ BR,BA,RE,HC,HA,GO,NHOUR(200),NMIN(200),
     1 NSEC(200),DEBUG,NUM,NDAY(200),MO(200),NYR(200),ITITLE(80),
     2 NTITLE,IPLOT(17),IR,NMO(200)
      COMMON /CONT/ X(200),Y(200)
      INTEGER BR,BA,RE,HC,HA,GO,DEBUG
      DIMENSION MONTH(12),      IXTITL(78),IYTITL(80),IZTITL(80),ICH(200),
     1XD(200),YP(200),LOC1(18),LOC2(18),XDP(200),YPP(200)
      DOUBLE PRECISION SECSUB,X,Y
      DATA MONTH/'JAN','FEB','MAR','APR','MAY','JUN','JUL','AUG','SEP',
     1'OCT','NOV','DEC'/
C
```

```
C DOUBLE PRECISION VALUES IF NEED
C
      DO 777 I=1,NAR
       IF (IDFLAG EQ 3) GO TO 778
      XDKEP=SIGN(1 ,XD(I))
      YPKEP=SIGN(1 ,YP(I))
      XD(I)=AINT(ABS(XD(I))*10**5+ 5)/10**5
      YP(I)=AINT(ABS(YP(I))*10**IDFLAG+ 5)/10**IDFLAG
      XDP(I)=XD(I)/XDKEP
      YPP(I)=YP(I)/YPKEP
      XD(I)=DBLE(XDP(I))
      YP(I)=DBLE(YPP(I))
 778     X(I)=XD(I)
777   Y(I)=YP(I)
C
C   CHANGE INTEGER MONTHS TO ALPHA CHARACTER MONTHS
C
      DO 700 I=1,NAR
      IF (MO(I) EQ 1) NMO(I)=MONTH(1)
      IF (MO(I) EQ 2) NMO(I)=MONTH(2)
      IF (MO(I) EQ 3) NMO(I)=MONTH(3)
      IF (MO(I) EQ 4) NMO(I)=MONTH(4)
      IF (MO(I) EQ 5) NMO(I)=MONTH(5)
      IF (MO(I) EQ 6) NMO(I)=MONTH(6)
      IF (MO(I) EQ 7) NMO(I)=MONTH(7)
      IF (MO(I) EQ 8) NMO(I)=MONTH(8)
      IF (MO(I) EQ 9) NMO(I)=MONTH(9)
      IF (MO(I) EQ 10) NMO(I)=MONTH(10)
      IF (MO(I) EQ.11) NMO(I)=MONTH(11)
      IF (MO(I) EQ 12) NMO(I)=MONTH(12)
700   CONTINUE
C
C ASSIGN CONSTANT VALUES
C
      XOFF=2
      YOFF=2
      NEND=0
      N=0
      L=0
      K=1
      HI=0 15
      J=1
C
C DO LOOP 2 MAKES A CONTINUES TIME ARRAY FROM INPUT OF YEAR,MONTH,DAY,
C  HOUR,MINUTE,AND SECOND OF EACH POINT
C
      DO 2 I=1,NAR
      N=N+1
      NHRMIN(I)=NHOUR(I)*100+NMIN(I)
      HR(I)=NHOUR(I)/100
      DAY(I)=NDAY(I)
      YEAR(I)=NYR(I)+1900
      IF (IT EQ 0) GO TO 2
115   CONTINUE
      NCONT = NHRMIN(I)
      IF (NHRMIN(I) EQ -999) NCONT=1600
      L=L+1
      IF (I EQ 1 AND J EQ 1) GO TO 19
      IF (NDAY(I) EQ NDSAVE) K=K+1
      NCONT=NCONT+(2400*(L-K))
      IF (NDAY(I) EQ NDSAVE) GO TO 107
      IF (NMO(I) NE MOSAVE) GO TO 108
      NDAGAP=NDAY(I)-NDSAVE
      GO TO 102
```

```
108     IF (MOSAVE EQ.MONTH(1).OR.MOSAVE.EQ.MONTH(3).OR MOSAVE.EQ MONTH(5)
      1 OR.MOSAVE EQ.MONTH(7) OR MOSAVE.EQ MONTH(8) OR.MOSAVE EQ
      2MONTH(10) OR.MOSAVE EQ MONTH(12)) MEND=31
        IF (MOSAVE.EQ MONTH(4) OR MOSAVE EQ MONTH(6) OR MOSAVE EQ.MONTH(9)
      1 OR MOSAVE EQ MONTH(11)) MEND=30
       DIV=NYSAVE/4
       IDV=NYSAVE/4.
       DIFF=DIV-IDV
        IF (DIFF NE 0 0 AND MOSAVE EQ.MONTH(2)) MEND=28
        IF (DIFF EQ 0 0 AND MOSAVE EQ.MONTH(2)) MEND=29
       NDAGAP=((MEND-NDSAVE)+NDAY(I))
       GO TO 102
107    NDAGAP=1
102    NCONT=NCONT+(2400*(NDAGAP-1))
       L=L+(NDAGAP-1)
 19    NHR=NCONT/100
       SECNHR=NHR*3600
       SECNMN=(NCONT-(NHR*100))*60.
       SECSUB(I)=SECNHR+SECNMN+NSEC(I)
       IF (J EQ 1) SECSAV=SECSUB(1)
       NDSAVE=NDAY(I)
       MOSAVE=NMO(I)
       NYSAVE=NYR(I)
 2     LAST=I
C
C DO LOOP 800 REASSIGNS TIME ARRAY SUCH THAT T(1)=0
C
155    DO 800 I=1,LAST
800    SECSUB(I)=SECSUB(I)-SECSAV
C
C     LOAD 'XD' AND 'YP' INTO 'X' AND 'Y'
C
       DO 3 I=1,NAR
       Y(I)=YP(I)
       IF (IT EQ 1) GO TO 4
       X(I)=XD(I)
       GO TO 3
   4   X(I)=SECSUB(I)
  3    CONTINUE
       IF (IT) 900,117,116
116    CONTINUE
       CALL TAXIS (J,N,LAST,XSCALE,XOFF,YOFF,HL,ISTHD)
       GO TO 805
117    CONTINUE
805    CALL GNPLOT   (N,     XOFF,YOFF,ITITLE,NTITLE,IXTITL,NXTITL,IYTITL,
      1 NYTITL,J,LAST,IT,NEND,XSCALE,YSCALE,HL,IZTITL,NZTITL,ICH,IDFLAG,
      2LOC1,LOC2,ISTHD)
       GO TO 910
900    CONTINUE
910    CONTINUE
       WRITE (33,192)
192    FORMAT(' ','END PLOT')
       RETURN
       END
       SUBROUTINE GNPLOT   (N,     XOFF,YOFF,ITITLE,NTITLE,IXTITL,NXTITL,
      1  IYTITL,NYTITL,J,LAST,IT,NEND,XSCALE,YSCALE,HL,IZTITL,NZTITL,
      2ICH,IDFLAG,LOC1,LOC2,ISTHD)
       COMMON /CONT/ X(200),Y(200)
C *******************************************************************
C *
C *
C *      THIS SUBROUTINE WAS ADAPTED TO DATA1'S NEFDS JULY,1977 BY        *
C * J E WOLFE FROM PRE-EXISTING PROGRAMS BY SAME   GNPLOT PLOTS THE DATA*
C * WRITES THE EXPLANATIONS, AND ANNOTATES DECIMAL AXES                 *
```

```
C *
C *
C ***********************************************************************
       DIMENSION ICH(N),            XPLOT(1000), YPLOT(1000), XPT(100),
      1 YPT(100), XYDIV(100), YYDIV(100),XPAN(100), YPAN(100),
      2ITITLE(NTITLE),IXTITL(NXTITL),IYTITL(NYTITL),IZTITL(NZTITL)
      3,LOC1(18),LOC2(18)
       DOUBLE PRECISION X,Y
       DATA IBL/' '/, ISTAR/'*'/
        AR=HL*2
       IEND=0
       IIEND=0
       XDIV=5
       YDIV=5.
       WRITE (33,191)
191    FORMAT(' ','FLAG2')
       CALL AAXS (Y,YDIV,YMIN,YLENTH,YPT,N2,YYDIV,N,YP1   ,JDEC,JDYPAS,
      1IDFLAG,NYPASS)
       YL=YLENTH*YSCALE+YOFF
       CALL PLOT (XOFF,YOFF,3)
       CALL PLOT (XOFF,YL,2)
       DO 6 I=1,N2
       YDR1=XOFF+.125
       YDR2=XOFF- 125
       YPAN(I)=YYDIV(I)*YSCALE+YOFF
       YAXNUM=XOFF-0 9     '
       YYAXNM=YPAN(I)-HL/2
       IF(I EQ 1) GO TO 3
       IF(YYAXNM LT YLOC+HL+(HL*0 4)) GO TO 6
3      CALL PLOT (YDR1,YPAN(I),3)
       CALL PLOT (YDR2,YPAN(I),2)
       CALL NUMBER (YAXNUM,YYAXNM,HL , YPT(I),0 ,JDEC)
       CALL WHERE(XLOC,YLOC,SIZE)
6      CONTINUE
       IF (IT EQ 1) GO TO 900
       WRITE (33,192)
 192   FORMAT(' ','CFLAG2')
116    CALL AAXS (X,XDIV,XMIN,XLENTH,XPT,N1,XYDIV,N,YP2   ,JDEC,JDXPAS,
      1IDFLAG,NXPASS)
       XL=XLENTH *XSCALE+XOFF
       CALL PLOT (XOFF,YOFF,3)
       CALL PLOT (XL,YOFF,2)
       DO 5 I=1,N1
       XDR1=YOFF+ 125
       XDR2=YOFF- 125
       XPAN(I)=XYDIV(I)*XSCALE+XOFF
       CALL PLOT (XPAN(I),XDR1,3)
       CALL PLOT (XPAN(I),XDR2,2)
       XAXNUM=YOFF- 5
       XXAXNM=XPAN(I)-HL
 5     CALL NUMBER (XXAXNM,XAXNUM,HL ,XPT(I),0 ,1)
       GO TO 115
900    XL= X(N)          *XSCALE+XOFF
       CALL PLOT (XL,YOFF,3)
       CALL PLOT (XOFF,YOFF,2)
115    IARRW=0
       IF (IT EQ 1) XMIN  =0
       HLS=HL*0 3
       DO 2 I=1,N
       XPLOT(I)=(X(I)-XMIN  )*XSCALE+XOFF
       YPLOT(I)=(Y(I)-YMIN  )*YSCALE+YOFF
       IF (I EQ 1) GO TO 12
13     CALL PLOT (XPLOT(I),YPLOT(I),2)
       CALL SYMBOL  (XPLOT(I),YPLOT(I),HLS,0,0.,-1)
```

```
      GO TO 2
12    CALL PLOT (XPLOT(1),YPLOT(1),3)
      HLS=HL*0.3
      CALL SYMBOL (XPLOT(1),YPLOT(1),HLS,0,0 ,-1)
 2    CONTINUE
      YA=YL+0.51*AR
      DO 10 I=1,N
      IF (ICH(I).NE.ISTAR) GO TO 10
      IARRW=IARRW+1
      SQ=(-1)**IARRW/2
      ISN=218.6+SQ
      XPAR=XPLOT(I)
      IF (ISN.EQ.219) XPAR=XPLOT(I)-AR*0.57
      CALL SYMBOL (XPAR     ,YL,AR,ISN,0.,-1)
      CALL SYMBOL(XPLOT(I),YA,AR,13,0.,-1)
10    CONTINUE
11    HTL = 1.2*HL
      YTITLE=YL+0.95+HTL
      XTITLE=XOFF-0.9
      IF(ISTHD.EQ.1.OR.ISTHD.EQ.3) CALL SYMBOL(XTITLE,YTITLE,HTL,
     1ITITLE,0.,NTITLE)
      YLOCC=YTITLE-.6
      IF(ISTHD.EQ.1.OR.ISTHD.EQ.3) CALL SYMBOL(XTITLE,YLOCC,HTL,LOC1,
     10.,12)
      CALL WHERE(XLOC,YLOC,SIZE)
      XLOCC=XL-(.81*HTL*12)
      IF(ISTHD.EQ.1.OR.ISTHD.EQ.3) CALL SYMBOL(XLOCC,YLOCC,HTL,LOC2,
     10.,18)
      YYAN=YL+.85
      XYAN=XTITLE
      CALL SYMBOL (XYAN,YYAN,HTL,IYTITL,0.  ,NYTITL)
      XYAN1=XYAN+(NYTITL+1)*0.81*HTL
      XYAN2=XYAN1+1.0*HTL
      YPI =YP1
      IF (YPI.EQ.0.) NYPASS=3
      CALL SYMBOL (XYAN1,YYAN,HTL,122,0.,-1)
      CALL NUMBER (XYAN2,YYAN,HTL,YPI,0.  ,JDYPAS)
      XYAN3=XYAN2+(NYPASS+0.5)*HTL*0.81
      CALL SYMBOL (XYAN3,YYAN,HTL,IZTITL,0.,NZTITL)
510   YXAN=YOFF-1.0
      XXAN=0.5+      XOFF
      IF (IT.EQ.1) GO TO 501
      IF (ISTHD.EQ.2.OR.ISTHD.EQ.3) CALL SYMBOL (XXAN,YXAN,HTL,IXTITL,
     10.,NXTITL)
      WRITE (33,193)
193   FORMAT(' ','GFLAG3')
501   RETURN
      END
      SUBROUTINE AAXS (Y,DIV,PMIN,PL    ,YDIV,N1,YYDIV,NAR,YPASS,JDEC,
     1JDYPAS,IDFLAG,NYPASS)
C ***********************************************************************
C *                                                                     *
C *                                                                     *
C *  THIS PROGRAM SEARCHES AN ARRAY FOR MAXIMUM AND MINIMUM VALUES ,    *
C * FINDS THE LENGTH OF THE RANGE OF VALUES IN AN ARRAY AND DIVIDES THE*
C * LENGTH INTO EQUAL PARTS WHICH RESULTS IN POINTS IN THE LENGTH WHICH*
C * ARE INTEGER VALUES  THIS PROGRAM CAN BE PUT INTO A PLOTTING SUB-    *
C * ROUTINE AND WILL PRODUCE EVEN INTEGER DIVISIONS OF ANY AXIS        *
C *  PROGRAM WAS WRITTEN BY J E WOLFE JUNE 30, 1977                    *
C *                                                                     *
C *                                                                     *
C ***********************************************************************
      DIMENSION YYDIV(100),YDIV(100),Y(200)
      DOUBLE PRECISION Y,YI1,YMAX,YMIN,TYMAX,TYMIN,YPASS,RR
```

```
      N1=DIV+1
      JJ=7
      WRITE (33,191)
191   FORMAT(' ','FLAG3')
C
C FIND MAXIMUM AND MINIMUM IN ARRAY
C
      YMAX=-999999.
      YMIN=999999.
      DO 2 I=1,NAR
      IF (Y(I) GT YMAX) YMAX=Y(I)
      IF (Y(I) LT.YMIN) YMIN=Y(I)
 2    CONTINUE
      RR=YMAX-YMIN
      NOTE=0
      IF (YMAX EQ YMIN) GO TO 762
      DO 200 I=1,20
      IF (NOTE EQ 1) GO TO 202
      YII=1 /1.0D 01**(I-1)
      GO TO 203
202   YII=1 0D 01**(I-1)
203   TYMAX=YMAX*YII
      TYMIN=YMIN*YII
      IF(TYMAX GT 8388607 OR TYMIN LT.-8388608 ) GO TO 252
      IF(TYMAX GE.0 ) IYMAX=IDINT(TYMAX+ 01)
      IF(TYMAX LT 0 ) IYMAX=IDINT(TYMAX- 01)
      IF(TYMIN GE 0 ) IYMIN=IDINT(TYMIN+ 01)
      IF(TYMIN.LT 0 ) IYMIN=IDINT(TYMIN- 01)
      IF (IYMAX EQ IYMIN AND I EQ 1) GO TO 210
      GO TO 207
210   NOTE=1
      GO TO 205
207   IF (IYMAX EQ IYMIN) GO TO 205
      IF (NOTE EQ 1) GO TO 252
205   XDEC=TYMAX-IYMAX
      ZDEC=TYMIN-IYMIN
      IF (IYMAX EQ IYMIN AND NOTE EQ 0) GO TO 252
 200  CONTINUE
252    JDEC=IDFLAG
      IF (NOTE EQ 1) GO TO 271
      Y1M=ABS(XDEC*10**(I-1))+ 000001
      Y2M=ABS(ZDEC*10**(I-1))+ 000001
      GO TO 272
271   Y1M=ABS(XDEC/10**(I-2))+ 000001
      Y2M=ABS(ZDEC/10**(I-2))+ 000001
272   IF(XDEC NE 0 ) Y1M=SIGN(Y1M,XDEC)
      IF(ZDEC NE 0 ) Y2M=SIGN(Y2M,ZDEC)
767   MAX=Y1M*10**JDEC
      MIN=Y2M*10**JDEC
769   MLO=MIN/10
      MML=MIN-MLO*10
      IF(MIN LT 0) MLO=MLO-1
      MIN=MLO*10
      IF (MML GE 5 AND MIN GE 0 OR.MIN.LT.0 AND.MML.GE -5) MIN=MIN+5
      LENGTH=MAX-MIN
      DO 3 K=1,20
      IF (K NE.1) LENGTH=LENGTH+1
      YINCR=LENGTH/DIV
      INCR=YINCR
      DIFF=YINCR-INCR
      IF (DIFF EQ.0) GO TO 4
  3   CONTINUE
  4   CONTINUE
      IF (NOTE EQ 1) GO TO 285
```

```
       YPASS=IYMIN*10**(I-1)
       JDYPAS=1
       GO TO 286
 285   IIN1=IYMIN/10
       YPASS=IIN1/10.0D 00**(I-2)
       IF(TYMAX GT 8388607  OR.TYMIN LT.-8388607 )YPASS=IYMIN/10.D 00**(I
      8-2)
       IF (JDYPAS LT.1) JDYPAS=1
 286   YYMIN=MIN
       DO 208 K=1,20
       YPLP=YPASS/10**(K-1)
       IF(ABS(YPLP).LT 1) GO TO 206
  208  CONTINUE
  206  K=K-1
       NYPASS=K+1+JDYPAS
       DO 800 J=1,N1
       K=J-1
       YYDIV(J)=YINCR*K
 800   YDIV(J)=YYMIN+YYDIV(J)
       XM2=0
       DO 836 K=1,10
       IF(NOTE EQ 0) NSF=JDEC+(I-1)
       IF(NOTE EQ 1) NSF=JDEC
       IF(JDEC EQ 3) NSF=2
       IF(NSF LE 2) MMINY=AINT(YDIV(1)/10.)*10
       IF(NSF LE 2 AND YDIV(1).LT 0.) MMINY=YDIV(1)
       IF(NSF EQ 3) GO TO 891
       IF(NSF EQ 4) GO TO 892
       IF(NSF EQ 5) GO TO 893
       IF(NSF EQ 6) GO TO 894
       IF(NSF EQ 7) GO TO 895
       IF(NSF EQ 8) GO TO 896
       GO TO 899
 891   XM1=AINT(YDIV(1)/100 )*100
       IF (LENGTH LT 50) XM1=AINT(YDIV(1)/10 )*10
       XMM=XM1+XM2*(K-1)
       XM2=10
       GO TO 898
 892   XM1=AINT(YDIV(1)/1000 )*1000.
       XMM=XM1+XM2*(K-1)
       XM2=100
       GO TO 898
 893   XM1=AINT(YDIV(1)/10000 )*10000
       XMM=XM1+XM2*(K-1)
       XM2=1000
       GO TO 898
 894   XM1=AINT(YDIV(1)/100000.)*100000
       XMM=XM1+XM2*(K-1)
       XM2=10000
       GO TO 898
 895   XM1=AINT(YDIV(1)/1000000 )*1000000
       XMM=XM1+XM2*(K-1)
       XM2=100000
       GO TO 898
 896   XM1=AINT(YDIV(1)/10000000 )*10000000.
       XMM=XM1+XM2*(K-1)
       XM2=1000000
       GO TO 898
 898   XM=YDIV(1)-XM1
       IF(YDIV(1) GE XMM) GO TO 835
       GO TO 899
 835   MMINY=XMM
 836   CONTINUE
  899     N2=0
```

```
C
C
C LOOP '801' DETERMINES THE NUMBER OF ANNOTATION VALUES ON THE AXIS
C YDIV ARRAY IS THE ANNOTATION NUMBERS  IF WANT LESS VALUES ON THE AXIS,
C CHANGE VALUE OF MADD  E G.. FOR FACTOR OF TEN LESS, SET MADD=(J-1)*100
C
C
      DO 801 J=1,100
      YDSAVE=MAX
      MADD=(J-1)
      IF(LENGTH LT 50.AND LENGTH GE 10) GO TO 881
      IF(LENGTH LT 100 AND LENGTH GE 50) GO TO 882
      IF(LENGTH LT 500 AND LENGTH GE 100) GO TO 883
      IF(LENGTH LT 1000 AND LENGTH GE 500) GO TO 884
      IF(LENGTH LT 5000 AND LENGTH GE 1000) GO TO 885
      IF(LENGTH LT 10000.AND LENGTH GE 5000) GO TO 886
      IF(LENGTH LT 50000 AND LENGTH GE 10000) GO TO 887
      IF(LENGTH LT 100000 AND LENGTH GE 50000) GO TO 888
      GO TO 890
881   YDSAVE=MAX+5
      MADD=(J-1)*5
      GO TO 890
882   YDSAVE=MAX+10
      MADD=(J-1)*10
      GO TO 890
883   YDSAVE=MAX+5*10
      MADD=(J-1)*5*10
      GO TO 890
884   YDSAVE=MAX+10**2
      MADD=(J-1)*10**2
      GO TO 890
885   YDSAVE=MAX+5*10**2
      MADD=(J-1)*5*10**2
      GO TO 890
886   YDSAVE=MAX+10**3
      MADD=(J-1)*10**3
      GO TO 890
887   YDSAVE=MAX+5*10**3
      MADD=(J-1)*5*10**3
      GO TO 890
888   YDSAVE=MAX+10**4
      MADD=(J-1)*10**4
 890  YDIV(J)=MNINY+MADD
      IF(J EQ 1) MIN=YDIV(1)
      YYDIV(J)=YDIV(J)-MIN
      IF (YDIV(J) GT YDSAVE) GO TO 802
      YDIV(J)=YDIV(J)      /10**JDEC
      YYDIV(J)=YYDIV(J)      /10**JDEC
801   N2=N2+1
802   N1=N2
      WRITE (33,120)
120   FORMAT(' ','ANNOTATION VALUES')
      WRITE (33,101)(YDIV(J),J=1,N1)
101   FORMAT(' ',7F9 3)
      YYMIN=MIN/10 **JDEC
      DO 112 K=1,NAR
112   Y(K)=Y(K)-YPASS
      PMIN=YYMIN
      PI=YDIV(N1)-YDIV(1)
      WRITE (33,777) YPASS
777   FORMAT(' ','YPASS ',D17 1)
      WRITE (33,777) (Y(K),K=1,NAR)
      GO TO 761
762   N1=1
```

```
      YDIV(1)=YMIN
      YYDIV(1)=0
      PMIN=YMIN
      PL=0
      YPASS=0
      JDEC=IDFLAG
      JDYPAS=1
761   RETURN
      END
      SUBROUTINE TAXIS (J,N,LAST,XSCALE,XOFF,YOFF,HL,ISTHD)
C *********************************************************************************
C *                                                                               *
C *                                                                               *
C *      THIS SUBROUTINE WAS ADAPTED TO DATA1'S NEEDS JULY, 1977 BY               *
C * J E WOLFE FROM PRE-EXISTING PROGRAMS BY SAME   TAXIS FINDS A SUIT-            *
C * ABLE TIME-AXIS ANNOTATION INTERVAL FROM THE LENGTH OF TIME OVER               *
C * WHICH THE DATA ARE TAKEN AND WRITES THE VALUES ON THE X-AXIS, IN-             *
C * CLUDING THE BEGINNING AND ENDING TIMES   TAXIS CHECKS FOR ANNOTA-             *
C * TION OVERLAPS FROM THESE TWO TIMES AND ELIMINATES SUCCEEDING AND              *
C * PRECEDING VALUES, RESPECTIVELY IN THE EVENT OF AN OVERLAP                     *
C *                                                                               *
C *                                                                               *
C *********************************************************************************
      COMMON/TAX/ NHRMIN(200),HR(200),DAY(200),YEAR(200),SECSUB(200)
      COMMON /LASER/BR,BA,RE,HC,HA,GO,NHOUR(200),NMIN(200),
     1 NSEC(200),DEBUG,NUM,NDAY(200),MO(200),NYR(200),ITITLE(80),
     2 NTITLE,IPLOT(17),IR,NMO(200)
      DOUBLE PRECISION SECSUB
      INTEGER BR,BA,RE,HC,HA,GO,DEBUG
      INTEGER H,D,M,MINUTE
      DATA H/'H'/,D/'D'/,M/'M'/,MINUTE/'MIN'/
      WRITE (33,191)
191   FORMAT(' ','TFLAG1')
      YHI=YOFF+ 125
      YLO=YOFF- 125
      HY1=YOFF- 33
      HY2=YOFF- 66
      HY3=YOFF- 99
      ICFLAG=0
      ISANA=NMIN(1)/10
      HRMIN1=NHRMIN(1)
      HRMINL=NHRMIN(N)
      SECL=NSEC(N)
      CSECL=SECSUB(N)*XSCALE+XOFF
      HTL=1 2*HL
      SP1=HTL*0 8
      SP2=HL*0 8
      XOLH=XOFF-HL*0 25
      DO 10 I=1,LAST
      HRP=NHOUR(I)
      BMIN=NMIN(I)
      SSEC=NSEC(I)
      SMIN=(NHRMIN(I)-HR(I))*60
      SHR=NHOUR(I)*3600 +SMIN
      SDAY=(NDAY(I)-1)*3600.*24.+SHR+SMIN
      IF (J EQ 1  AND I EQ 1) GO TO 5
      GO TO 1
  5   LOAN=M
      IF (SECSUB(LAST) LE 864000) LOAN=D
      IF (SECSUB(LAST) LE 18000) LOAN=H
      IF (SECSUB(LAST) LE 7200) LOAN=MINUTE
      CALL PLOT (XOFF,YHI,3)
      CALL PLOT (XOFF,YLO,2)
      XH1=XOFF-2 5*SP2
```

```
      XH2=XH1
      IF (HRP LT 10 ) XH1=XH1+SP2
      CALL NUMBER (XH1,HY1,HL,HRP,0.,-1)
      CALL SYMBOL (XOLH,HY1,HL,122,0.,-1)
      XM1=XOFF+0 5*SP2
      CALL NUMBER (XM1,HY1,HL,BMIN,0.,-1)
      CALL WHERE (XLOC,YLOC,SIZE)
      IF( ISTHD EQ 1 OR ISTHD.EQ.4) GO TO 80
      CALL SYMBOL (XH2,HY2,HL,'HR',0 ,2)
      CALL SYMBOL (XOLH,HY2,HL,122,0 ,-1)
      CALL SYMBOL (XM1,HY2,HL,'MIN',0 ,3)
      XANN=SP1*5  +XOFF
      CALL SYMBOL (XANN,HY2,HTL,'GMT-10HR',0.,8)
      CALL WHERE(XKEEP,YKEEP,SIZE)
      GO TO 80
      CONTINUE
      IF (LOAN NE MINUTE.OR ICFLAG.EQ 1) GO TO 16
      NA=NMIN(I)/10
      IF (ISANA EQ NA) GO TO 16
      NB=NMIN(I)-(NA*10)
      DO 15 K=NA,5
      KK=K-NA
      HX=(SECSUB(I)-(NB*60+SSEC)+600*KK)*XSCALE+XOFF
      IF (HX GT CSLCL) GO TO 17
      XMINA1=HRP
      XMINA2=K*10
      XA1=HX-2 5*SP2
      XA2=HX+0 5*SP2
      XA3=XA2+(2*SP2)
      IF(XA3 GE CSECL-(SP2*1 5)) GO TO 15
      CALL PLOT (HX,YHI,3)
      CALL PLOT (HX,YLO,2)
      IF (XA1 LT XLOC+SP2) GO TO 15
      IF(XMINA1 LT 10 ) XA1=XA1+SP2
      CALL NUMBER (XA1,HY1,HL,XMINA1,0 ,-1)
      HZ=HX-HL*0 25
      CALL SYMBOL (HZ,HY1,HL,122,0 ,-1)
      CALL NUMBER (XA2,HY1,HL,XMINA2,0 ,-1)
15    CALL WHERE (XLOC,YLOC,SIZE)
17    ICFLAG=1
16    CONTINUE
      IF (LOAN NE H AND LOAN.NE MINUTE) GO TO 60
      IF (NHOUR(I) EQ NHRSAV) GO TO 60
      HX=(SECSUB(I)-SMIN-SSEC)*XSCALE+XOFF
      XA1=HX-2 5*SP2
      XA2=HX+0 5*SP2
      IF (XA1 LT XLOC+SP2 OR XA2+3*SP2 GT.CSECL-2*SP2) GO TO 505
      CALL PLOT (HX,YHI,3)
      CALL PLOT (HX,YLO,2)
      IF (HRP LT 10 ) XA1=XA1+SP2
      CALL NUMBER (XA1,HY1,HL,HRP,0 ,-1)
      HZ=HX-HL*0 25
      CALL SYMBOL (HZ,HY1,HL,122,0.,-1)
      CALL NUMBER(XA2,HY1,HL,0.,0 ,-1)
505   CALL WHERE (XLOC,YLOC,SIZE)
      IF (LOAN NE MINUTE) GO TO 60
      DO 58 J=1,5
      HX=(SECSUB(I)-SMIN-SSEC+ 600*J)*XSCALE+XOFF
      IF (HX GT CSECL     ) GO TO 60
      XMINA1=HRP
      XMINA2=J*10
      XA1=HX-2 5*SP2
      XA2=HX+0 5*SP2
      IF (XA1 LT XLOC+SP2 OR XA2+3*SP2 GT CSECL-2*SP2) GO TO 58
```

```
      CALL PLOT (HX,YHI,3)
      CALL PLOT (HX,YLO,2)
      IF(XMINA1 LT 10 ) XA1=XA1+SP2
      CALL NUMBER (XA1,HY1,HL,XMINA1,0.,-1)
      HZ=HX-HL*0 25
      CALL SYMBOL (HZ,HY1,HL,122,0 ,-1)
      CALL NUMBER (XA2,HY1,HL,XMINA2,0 ,-1)
58    CALL WHERE (XLOC,YLOC,SIZE)
60    CONTINUE
      IF (LOAN EQ M) GO TO 70
      IF (NDAY(I).EQ NDASAV) GO TO 70
      HX=(SECSUB(I)-SHR-SSEC)*XSCALE+XOFF
      IF (HX LT.XKEEP+SP2*4) GO TO 65
      CALL PLOT (HX,YHI,3)
      CALL PLOT (HX,YLO,2)
      CALL NUMBER (HX,HY2, HL,DAY(I),0 ,-1)
65    CALL WHERE(XLOC,YLOC,SIZE)
70    CONTINUE
      IF (NMO(I) EQ MONSAV) GO TO 75
      HO=(SECSUB(I)-SDAY-SSEC)*XSCALE+XOFF
      HX=HO+3 *HL
      IF (LOAN EQ M) HX=HO
      CALL PLOT(HO,YHI,3)
      CALL PLOT (HO,YLO,2)
      IF (HX LT XKEEP+4*SP2) HY2=HY3
      CALL SYMBOL (HX,HY2, HL,NMO(I),0 ,3)
      HY2=YOFF- 66
      CALL WHERE (XLOC,YLOC,SIZE)
75    CONTINUE
      IF (NYR(I) EQ NYRSAV) GO TO 80
      HX=HO
      CALL PLOT(HX,YHI,3)
      CALL PLOT(HX,YLO,2)
      IF(HX LT XKEEP+4*SP2) HY3=YOFF-1.32
      CALL NUMBER (HX,HY3,HL ,YEAR(I),0.,-1)
      HY3=XOFF- 99
80    NHRSAV=NHOUR(I)
      NDASAV=NDAY(I)
      MONSAV=NMO(I)
10    NYRSAV=NYR(I)
      XLNBH=SECSUB(N)*XSCALE+XOFF
      CALL PLOT (XLNBH     ,YHI,3)
      CALL PLOT (XLNBH     ,YLO,2)
      XA1=XLNBH-2 5*SP2
      XA2=XLNBH+0 5*SP2
      IF (HRP LT 10 ) XA1=XA1+SP2
      CALL NUMBER (XA1,HY1,HL,HRP,0 ,-1)
      HLNLH=XLNBH-HL*0 25
      CALL SYMBOL (HLNLH ,HY1,HL,122,0 ,-1)
      CALL NUMBER (XA2,HY1,HL,BMIN,0 ,-1)
      WRITE (33,200)
200   FORMAT (' ','TFLAG10')
      RETURN
      END
```

APPENDIX IV
OTHER COMPUTER PROGRAMS

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C        PROGRAM TO REDUCE A SPATIAL DISTANCE TO A UNIVERSAL TRANS-    C
C     VERSE MERCATOR PLANE DISTANCE  WRITTEN BY B  SCHENCK, AUG  1977  C
C                                                                      C
C        THE PROGRAM TAKES TWO DATA CARDS AS INPUT FOR EACH SEPARATE   C
C     LINE TO BE COMPUTED  THE FIRST CARD OF THE PAIR MAY CONTAIN THE  C
C     NAME OF THE LINE, AND WILL BE PRINTED AT THE TOP OF THAT SECTION C
C     OF THE OUTPUT  THE SECOND CARD OF EACH PAIR MUST CONTAIN THE     C
C     FOLLOWING  COLUMNS 1-10 CONTAIN THE SPATIAL CHORD DISTANCE,      C
C     "BIGDC", IN AN F10 3 FORMAT; COLS  11-30 CONTAIN THE ELEVATIONS  C
C     OF THE TWO ENDPOINTS, "H1" & "H2", IN TWO F10 2 FORMATS, COLS    C
C     31-50 CONTAIN THE "X" PLANE COORDINATES OF EACH POINT OF THE     C
C     LINE, IN TWO F10 1 FORMATS, COLS  51-55 CONTAIN THE AZIMUTH OF   C
C     THE LINE  IN AN F5 1 FORMAT, COLS  56-75 CONTAIN THE LATITUDE IN C
C     DECIMAL DEGREES OF EACH POINT, IN TWO F10 6 FORMATS  THE FINAL   C
C     DATA CARD MUST CONTAIN A "1" IN COLUMN *80  OUTPUT FOR EACH LINE C
C     IS. THE INFORMATION ON THE FIRST DATA CARD OF EACH PAIR, THE     C
C     SPATIAL CHORD DISTANCE, THE ELEVATIONS OF THE ENDPOINTS, THE     C
C     ELLIPSOIDAL ARC DISTANCE, "DA"; AND THE UTM MAP DISTANCE, "DM2"  C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C***  THIS SECTION INITIALIZES VARIABLES AND READS INPUT
      DIMENSION XLINE(12)
      DOUBLE PRECISION BIGDC,H1,H2,RA,W,DSIN,ESQ,AZ,X1,X2,DSQRT,
     1CLAT1,CLAT2,CLAT,DCOS,PI,REDUCT,U,DAA,DA,DM2,SCLAT,AM,AN,A
      REDUCT=0 9999667D 0
      PI=3 1415926535898D 0
      A=6378206 4D 0
      ESQ=0 006768658D 0
  200 READ (8,103) (XLINE(I),I=1,12)
  103 FORMAT (12A6)
      WRITE (9,104)
  104 FORMAT (' LINE REDUCTION ONTO TM PLANE OF ')
      WRITE (9,103) XLINE
      READ (8,100) BIGDC,H1,H2,X1,X2,AZ,CLAT1,CLAT2,N
  100 FORMAT (F10 3,2F10 2,2F10 1,F5.1,2F10 6,T80,I1)
      WRITE (9,101) BIGDC,H1,H2
  101 FORMAT (' SPATIAL CHORD DISTANCE =',5X,F10 3,/,' ELEVATIONS OF END
     1POINTS ARE ',5X,F8 2,2X,'AND',5X,F8 2)
C***  THIS SECTION COMPUTES THE MEAN OF THE LATITUDE OF THE ENDPOINTS,
C***  CONVERTS IT TO RADIANS AND TAKES THE SINE OF THE RESULT
      CLAT=(CLAT1+CLAT2)/2 /180 *PI
      SCLAT=DSIN(CLAT)**2
C***  THIS SECTION COMPUTES "W" USING THE FORMULA
C***     W=SQRT(1 -ESQ*(SINE(CLAT)**2))
      W=DSQRT(1 -ESQ*SCLAT)
C***  THIS SECTION COMPUTES "M" & "N" USING THE FORMULAS
C***     M=A(1 -E**2)/W**3, N=A/W, WHERE "A" IS THE SEMIMAJOR AXIS OF
C***  THE ELLIPSOID.
      AM=A*(1 +(-ESQ))/W**3
      AN=A/W
C***  THIS SECTION CONVERTS THE AZIMUTH OF THE LINE TO RADIANS, THEN
C***  COMPUTES THE CURVATURE RADIUS USING THE FORMULA
C***    RA=M*N/(M*SINE(AZ)**2+N*COSINE(AZ)**2)
      AZ=AZ/180 *PI
      RA=AM*AN/(AM*DSIN(AZ)**2+AN*DCOS(AZ)**2)
      WRITE (9,105) RA
  105 FORMAT (' CURVATURE RADIUS =',F12 2)
C***  THIS SECTION COMPUTES "U", THE ELLIPSOIDAL ARC DISTANCE, AND THE
C***  UTM MAP DISTANCE USING THE FORMULAS
C***     U=DC**2-(H1-H2)**2;
```

```
C***      DA=SQRT(2.*RA**2*U/(2.*(RA+H1)*(RA+H2)-U)),
C***      UTM=DA*(0.9999667*((X1**2+X1*X2+X2**2)/6./RA**2))
       U=BIGDC**2-(H1-H2)**2
       DAA=2.*RA**2*U/(2.*(RA+H1)*(RA+H2)-U)
       DA=DSQRT(DAA)
       DM2=DA*(REDUCT+((X1**2+X1*X2+X2**2)/6./RA**2))
       WRITE (9,107) DA,DM2
   107 FORMAT (' ELLIPSOIDAL ARC DISTANCE (EQ. 15.25) =',2X,F10.3,/,' UTM
      1 MAP DISTANCE =',2X,F10.3,/)
       IF (N.NE.1) GO TO 200
       STOP
       END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C         PROGRAM TO ADJUST LINE LENGTHS OF A QUADRILATERAL BY A LEAST  C
C      SQUARES METHOD OF ADJUSTMENT  WRITTEN BY BRUCE SCHENCK FEB  1978 C
C                                                                      C
C         THIS PROGRAM WAS WRITTEN SPECIFICALLY FOR QUADRILATERALS, BUT C
C      WITH A FEW MODIFICATIONS IT WILL WORK FOR ANY TYPE OF FIGURE     C
C      ALL CALCULATIONS ARE DONE IN DOUBLE PRECISION  THE QUADRILATERAL C
C      MUST BE ARRANGED AS SHOWN IN THE ADJOINING PLOT OR AS SHOWN IN   C
C      THE FIGURE BELOW                                                 C
C                                                                      C
C          C*-----------------------------*B                           C
C           I                              I                           C
C           I                              I    ANGLE (CAD)=ALPHA 1    C
C           I                              I    ANGLE (DBA)=ALPHA 2    C
C           I                              I    ANGLE (ACB)=ALPHA 3    C
C           I                              I    ANGLE (BDC)=ALPHA 4    C
C           I                              I    ANGLE (CAB)=BETA 1     C
C           I                              I    ANGLE (DBC)=BETA 2     C
C           I                              I    ANGLE (ACD)=BETA 3     C
C           I                              I    ANGLE (BDA)=BETA 4     C
C           I                              I    ANGLE (DAB)=GAMMA 1    C
C           I                              I    ANGLE (ABC)=GAMMA 2    C
C           I                              I    ANGLE (BCD)=GAMMA 3    C
C           I                              I    ANGLE (CDA)=GAMMA 4    C
C           I                              I    ANGLE (DAE)=DELTA 1    C
C           I              *               I    ANGLE (ABE)=DELTA 2    C
C           I              E               I    ANGLE (BCE)=DELTA 3    C
C           I                              I    ANGLE (CDE)=DELTA 4    C
C           I                              I    ANGLE (BAE)=THETA 1    C
C           I                              I    ANGLE (CBE)=THETA 2    C
C           I                              I    ANGLE (DCE)=THETA 3    C
C           I                              I    ANGLE (ADE)=THETA 4    C
C           I                              I    ANGLE (AEB)=PHI 1      C
C           I                              I    ANGLE (BEC)=PHI 2      C
C           I                              I    ANGLE (CED)=PHI 3      C
C           I                              I    ANGLE (DEA)=PHI 4      C
C           I                              I                           C
C           I                              I                           C
C           I                              I                           C
C           I                              I                           C
C          D*-----------------------------*A                           C
C                                                                      C
C      THE CORNERS MUST BE NUMBERED AS SHOWN, WITH THE CENTER POINT,    C
C      IF ANY, LETTERED E  THE DATA CARDS NEEDED ARE AS FOLLOWS  THE    C
C      FIRST CARD CAN CONTAIN ANY INFORMATION DESIRED  WHICH WILL BE    C
C      PRINTED AT THE TOP OF THE EXECUTED PORTION  THE SECOND DATA CARD C
C      CONTAINS "NTYPE" IN COLUMN 17  "NTYPE" IS A NUMBER WHICH TELLS   C
C      THE PROGRAM WHAT TYPE OF ADJUSTMENT IS DESIRED  NTYPE=1 MEANS    C
C      AN ADJUSTMENT OF A QUADRILATERAL WITH DIAGONALS ONLY, NTYPE=2    C
C      MEANS ADJUSTMENT OF A QUADRILATERAL WITH A CENTER POINT ONLY,    C
C      NTYPE=3 MEANS ADJUSTMENT OF A QUADRILATERAL WITH DIAGONALS AND   C
C      CENTER POINT COMBINED  THE THIRD AND FOURTH CARDS CONTAIN THE    C
C      LINE LENGTHS IN KILOMETERS INCLUDED IN THE QUADRILATERAL IN AN   C
C      F10.3 FORMAT  THE THIRD CARD MUST CONTAIN THE LENGTHS OF THE     C
C      FOLLOWING LINES IN THE FOLLOWING ORDER  AB, AC, AD, AE, BC  THE  C
C      FOURTH CARD MUST CONTAIN THE FOLLOWING LINES  BD, BE, CD, CE,    C
C      DE  IN THE PROGRAM "N" IS THE NUMBER OF CONDITIONS PRESENT.      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C***  THIS SECTION READS INPUT AND INITIALIZES VARIABLES
      IMPLICIT REAL*8 (A-H,K,O-Z)
      DIMENSION XADJ(20),MAM(6,4),MAD(6,4),K(3),AR(6,4),AQ(6,4),AM(6,4),
```

```
     1AS(6,4),W(3),P(10),R(10,3),CC(3,3),S(10),WW(3),CLOSE(3),Z(5),WS(3)
      EQUIVALENCE (AR(6,2),BEC),(AR(6,3),CED),(AR(6,4),DEA),(AR(1,1),A),
     1(AR(1,2),B),(AR(1,3),C),(AR(1,4),D),(AR(6,1),AEB),(NN,N),(P(1),PAB
     2),(P(2),PBC),(P(3),PCD),(P(4),PAD),(P(5),PAC),(P(6),PBD),(P(7),PAE
     3),(P(8),PBE),(P(9),PCE),(P(10),PDE)
      DATA R,CC/30*0.D0,9*0.D0/
      READ (8,100) XADJ
  100 FORMAT (20A4)
      READ (8,101) NTYPE
  101 FORMAT (T7,I1)
      PI=3.1415926535898D00
      NO=0
C*** NSID = NUMBER OF SIDES OF FIGURE BEING ADJUSTED
C*** NAN = NUMBER OF DIFFERENT TYPES OF ANGLES IN FIGURE BEING ADJUSTED,
C*** I.E. ALPHAS, BETAS, GAMMAS, ETC.
      NSID=4
      NNN=1
      NAN=3
      IF (NTYPE.EQ.2) NNN=4
      IF (NTYPE.NE.1) NAN=6
      N=1
      IF (NTYPE.EQ.3) N=3
      NL=10
      WRITE (9,100) XADJ
      READ (8,102) AB,AC,AD,AE,BC
      READ (8,102) BD,BE,CD,CE,DE
  102 FORMAT (5F10.7)
      WRITE (9,103) AB,AC,AD,AE,BC,BD,BE,CD,CE,DE
  103 FORMAT (/,' MEASURED LINE LENGTHS ',/,' AB=',F10.6,/,' AC=',F10.6,
     1/,' AD=',F10.6,/,' AE=',F10.6,/,' BC=',F10.6,/,' BD=',F10.6,/,' BE
     2=',F10.6,/,' CD=',F10.6,/,' CE=',F10.6,/,' DE=',F10.6)
  104 CONTINUE
C*** THIS SECTION COMPUTES EACH ANGLE OF THE FIGURE IN RADIANS AND IN
C*** DEGREES, MINUTES, AND SECONDS, BY USE OF THE COSINE LAW
      IF (NTYPE.EQ.2) GO TO 105
      AR(1,1)=ANGLE(AD,AB,BD)
      AR(1,2)=ANGLE(AB,BC,AC)
      AR(1,3)=ANGLE(BC,CD,BD)
      AR(1,4)=ANGLE(CD,AD,AC)
      AR(2,1)=ANGLE(AC,AD,CD)
      AR(2,2)=ANGLE(AB,BD,AD)
      AR(2,3)=ANGLE(AC,BC,AB)
      AR(2,4)=ANGLE(BD,CD,BC)
      AR(3,1)=ANGLE(AB,AC,BC)
      AR(3,2)=ANGLE(BC,BD,CD)
      AR(3,3)=ANGLE(AC,CD,AD)
      AR(3,4)=ANGLE(AD,BD,AB)
  105 CONTINUE
      IF (NTYPE.EQ.1) GO TO 106
      AR(4,1)=ANGLE(AD,AE,DE)
      AR(4,2)=ANGLE(AB,BE,AE)
      AR(4,3)=ANGLE(BC,CE,BE)
      AR(4,4)=ANGLE(CD,DE,CE)
      AR(5,1)=ANGLE(AB,AE,BE)
      AR(5,2)=ANGLE(BE,BC,CE)
      AR(5,3)=ANGLE(CE,CD,DE)
      AR(5,4)=ANGLE(AD,DE,AE)
      AR(6,1)=ANGLE(AE,BE,AB)
      AR(6,2)=ANGLE(BE,CE,BC)
      AR(6,3)=ANGLE(CE,DE,CD)
      AR(6,4)=ANGLE(AE,DE,AD)
  106 CONTINUE
      AEC=ANGLE(AE,CE,AC)
      BED=ANGLE(BE,DE,BD)
```

```
      ACE=ANGLE(AC,CE,AE)
      CAE=ANGLE(AC,AE,CE)
      DBE=ANGLE(BD,BE,DE)
      BDE=ANGLE(BD,DE,BE)
      DO 107 I=NNN,NAN
      DO 107 J=1,NSID
      AQ(I,J)=AR(I,J)*180./PI
      MAD(I,J)=AQ(I,J)
      AM(I,J)=(AQ(I,J)-MAD(I,J))*60
      MAM(I,J)=AM(I,J)
  107 AS(I,J)=(AM(I,J)-MAM(I,J))*60.
      IF (NO.EQ.0) WRITE (9,111)
  111 FORMAT (/,' CALCULATED ANGLES (RADIANS) ',T40,'CALCULATED ANGLES (
     . 1DEGREES) ')
      IF (NO.EQ.1) WRITE (9,142)
  142 FORMAT (/,' ADJUSTED ANGLES (RADIANS).',T40,'ADJUSTED ANGLES (DEGR
     1EES) ')
      IF (NTYPE.EQ.1) WRITE (9,108) ((AR(I,J),MAD(I,J),MAM(I,J),AS(I,J
     1),J=1,NSID),I=NNN,NAN)
      IF (NTYPE.EQ.2) WRITE (9,109) ((AR(I,J),MAD(I,J),MAM(I,J),AS(I,J
     1),J=1,NSID),I=NNN,NAN)
      IF (NTYPE.EQ.3) WRITE (9,110) ((AR(I,J),MAD(I,J),MAM(I,J),AS(I,J
     1),J=1,NSID),I=NNN,NAN)
  108 FORMAT (/,' GAMMA 1-4 ',T40,'GAMMA 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X
     1,F7.3,/),' ALPHA 1-4 ',T40,'ALPHA 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X,
     2F7.3,/),' BETA 1-4 ',T40,'BETA 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X,F7
     33,/))
  109 FORMAT (/,' DELTA 1-4 ',T40,'DELTA 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X
     1,F7.3,/),' THETA 1-4 ',T40,'THETA 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X,
     2F7.3,/),' PHI 1-4 ',T40,'PHI 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X,F7.3,
     3/))
  110 FORMAT (/,' GAMMA 1-4 ',T40,'GAMMA 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X
     1,F7.3,/),' ALPHA 1-4 ',T40,'ALPHA 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X,
     2F7.3,/),' BETA 1-4 ',T40,'BETA 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X,F7
     33,/),' DELTA 1-4 ',T40,'DELTA 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X,F7.3
     4,/),' THETA 1-4 ',T40,'THETA 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X,F7.3,
     5/),' PHI 1-4 ',T40,'PHI 1-4 ',/,4(D20.9,T40,I4,1X,I3,1X,F7.3,/))
C***  THIS SECTION CONTAINS THE CONDITIONS AND COMPUTES THE RESIDUALS
C***  BEFORE ADJUSTMENT IN RADIANS AND SECONDS
      IF (NTYPE.NE.2) W(1)=A+B+C+D-2.*PI
      IF (NTYPE.EQ.2) W(1)=AEB+BEC+CED+DEA-2.*PI
      IF (NTYPE.NE.3) GO TO 112
      W(2)=AEC+BEC+AEB-2.*PI
      W(3)=BED+BEC+CED-2.*PI
  112 CONTINUE
      DO 150 I=1,N
  150 WS(I)=W(I)*180./PI*3600
      IF (NO.EQ.0) WRITE (9,113)
  113 FORMAT (/,' ANGLE CONDITION CLOSURES (RADIANS):')
      IF (NO.EQ.1) WRITE (9,143)
  143 FORMAT (/,' ANGLE CONDITION CLOSURES AFTER ADJUSTMENT (RAD) ')
      WRITE (9,114) (I,W(I),WS(I),I=1,NN)
  114 FORMAT (I3,'.',D12.4,' = ',F7.3,'"')
      IF (NO.EQ.1) GO TO 141
      DO 125 I=1,N
  125 WW(I)=W(I)
C***  THIS SECTION COMPUTES THE NORMALS TO EACH LINE IN KILOMETERS
      IF (NTYPE.EQ.2) GO TO 120
      KAB=KORM1(AB,AD,BC,A,B)
      KCD=KORM1(CD,AD,BC,D,C)
      KBC=KORM1(BC,AB,CD,B,C)
      KAD=KORM1(AD,AB,CD,A,D)
      KAC=-KORM2(AC,AB,BC,B,CD,AD,D)
      KBD=-KORM2(BD,AD,AB,A,BC,CD,C)
```

```
      IF (NTYPE  NE  2) GO TO 115
  120 CONTINUE
      KAB=-KORM3(AB,AE,BE,AEB)
      KBC=-KORM3(BC,BE,CF,BEC)
      KCD=-KORM3(CD,CE,DE,CED)
      KAD=-KORM3(AD,DF,AE,DEA)
      KAE=KORM1(AE,DE,BE,AR(6,4),AR(6,1))
      KBE=KORM1(BE,AF,CE,AR(6,1),AR(6,2))
      KCF=KORM1(CF,BF,DF,AR(6,2),AR(6,3))
      KDE=KORM1(DE,CF,AF,AR(6,3),AR(6,4))
  115 CONTINUE
      IF (NTYPE  NE  3) GO TO 121
      KAB2=-KORM3(AB,AF,BF,AFB)
      KBC2=-KORM3(BC,BE,CF,BEC)
      KAC2=-KORM3(AC,AE,CE,AEC)
      KAE2=KORM1(AF,CE,BE,AFC,AEB)
      KBF2=KORM1(BF,AE,CE,AFB,BEC)
      KCE2=KORM1(CE,BF,AE,BFC,AEC)
      KBD3=-KORM3(BD,BF,BF,BFD)
      KBC3=-KORM3(BC,BE,CF,BFC)
      KCD3=-KORM3(CD,CE,DE,CFD)
      KDE3=KORM1(DE,CF,BF,CED,BFD)
      KBF3=KORM1(BF,DF,CF,BED,BEC)
      KCE3=KORM1(CE,BE,DE,BFC,CED)
  121 CONTINUE
      WRITE (9,116)
  116 FORMAT (/,' NORMALS TO LINES (KM) ')
      WRITE (9,117) KAB,KBC,KCD,KAD
  117 FORMAT (/,' KAB=',F10 6,/,' KBC=',F10 6,/,' KCD=',F10 6,/,' KAD=',
     1F10 6)
      IF (NTYPE  NE  2) WRITE (9,118) KAC,KBD
  118 FORMAT (' KAC=',F10 6,/,' KBD=',F10 6)
      IF (NTYPE  EQ  2) WRITE (9,119) KAE,KBE,KCF,KDE
  119 FORMAT (' KAE=',F10 6,/,' KBE=',F10 6,/,' KCF=',F10 6,/,' KDF=',
     1F10 6)
      IF (NTYPE  EQ  3) WRITE (9,122) KAB2,KBC2,KAC2,KAE2,KBF2,KCE2,KBC3
     1,KBD3,KCD3,KBF3,KCF3,KDE3
  122 FORMAT (' KAB2=',F10 6,/,' KBC2=',F10 6,/,' KAC2=',F10 6,/,' KAF2=
     1 ,F10 6,/,' KBF2=',F10 6,/,' KCE2=',F10 6,/,' KBC3=',F10 6, ,' KBD
     23=',F10 6,/,' KCD3 ',F10 6,/,' KBF3=',F10 6,/,' KCE3=',F10 6,/,' K
     3DE3=',F10 6)
C***  THIS SECTION COMPUTES THE WEIGHT OF EACH LINE ACCORDING TO THE
C***  DESIRED WEIGHT FUNCTION
      PAB=WEIGHT(AB)
      PBC=WEIGHT(BC)
      PCD=WEIGHT(CD)
      PAD=WEIGHT(AD)
      PAC=WEIGHT(AC)
      PBD=WEIGHT(BD)
      PAF=WEIGHT(AF)
      PBF=WEIGHT(BF)
      PCF=WEIGHT(CF)
      PDE=WEIGHT(DE)
      WRITE (9,123) PAB,PBC,PCD,PAD,PAC,PBD,PAF,PBF,PCE,PDE
  123 FORMAT (/,' INVERSE WEIGHTS OF LINES ',/,' PAB=',F8 3,/,' PBC=',F8
     1 3,/,' PCD=',F8 3,/,' PAD=',F8 3,/,' PAC=',F8 3,/,' PBD=',F8 3,/,'
     2 PAF=',F8 3,/,' PBF=',F8 3,/,' PCE=',F8 3,/,' PDE=',F8 3)
C      THIS SECTION INITIALIZES THE CORRELATE MATRIX
       IF (NTYPE  EQ  2) GO TO 131
C    CONDITION #1,NTYPE=1 OR 3,INITIALIZE
      R(1,1)=1 D0/KAB*PAB
      R(2,1)=1 D0/KBC*PBC
      R(3,1)=1 D0/KCD*PCD
      R(4,1)=1 D0/KAD*PAD
```

```
      R(5,1)=1 D0/KAC*PAC
      R(6,1)=1 D0/KBD*PBD
  131 CONTINUE
      IF (NTYPE NE 2) GO TO 132
C***CONDITION #1,NTYPE=2,INITIALIZE
      R(1,1)=1 D0/KAB*PAB
      R(2,1)=1.D0/KBC*PBC
      R(3,1)=1 D0/KCD*PCD
      R(4,1)=1 D0/KAD PAD
      R(7,1)=1 D0/KAE*PAE
      R(8,1)=1 D0/KBF*PBE
      R(9,1)=1 D0/KCE PCE
      R(10,1)=1 D0/KDE PDE
  132 CONTINUE
      IF (NTYPE NE 3) GO TO 133
C***CONDITION #2,NTYPE=3,INITIALIZE
      R(1,2)=1 D0/KAB2*PAB
      R(2,2)=1 D0/KBC2*PBC
      R(5,2)=1 D0/KAC2*PAC
      R(7,2)=1 D0/KAE2*PAF
      R(8,2)=1.D0/KBF2*PBF
      R(9,2)=1 D0/KCF2*PCF
C***CONDITION #3,NTYPE-3,INITIALIZE
      R(2,3)=1 D0/KBC3*PBC
      R(3,3)=1 D0/KCD3*PCD
      R(6,3)=1 D0/KBD3*PBD
      R(8,3)=1 D0/KBF3 PBE
      R(9,3)=1 D0/KCE3*PCF
      R(10,3)=1 D0/KDE3*PDE
  133 CONTINUE
C***  THIS SECTION SETS UP THE NORMAL EQUATIONS
      DO 500 L=1,NN
      DO 500 J=1,NN
      DO 500 I=1,NI
      S(I)=R(I,L)*R(I,J)/P(I)
  500 CC(L,J)=CC(L,J)+S(I)
C*** THIS SECTION CONSISTS OF A GAUSSIAN ELIMINATION PROCESS TO SOLVE
C***  THE NORMAL EQUATIONS FOR THE CORRELATES
      IF(N  NE  1) GO TO 4
      IF(CC(1,1)  EQ  0 ) GO TO 3
      K(1)=W(1)/CC(1,1)
      GO TO 202
    3 GO TO 203
    4 NLESS1=N-1
      DO 13 I=1,NLESS1
      BIG=ABS(CC(I,I))
      L=I
      IPLUS1=I+1
      DO 6 J=IPLUS1,N
      IF (ABS(CC(J,I))  LE  BIG) GO TO 6
      BIG=ABS(CC(J,I))
      L=J
    6 CONTINUE
      IF (BIG  NE  0 ) GO TO 8
      GO TO 203
    8 IF (L  EQ  I) GO TO 11
      DO 10 J=1,N
      TEMP=CC(L,J)
      CC(L,J)=CC(I,J)
   10 CC(I,J)=TEMP
      TEMP=W(I)
      W(L)=W(I)
      W(I)=TEMP
   11 DO 13 J=IPLUS1,N
```

```
      QUO1=CC(J,I)/CC(I,I)
      DO 12 M=IPLUS1,N
   12 CC(J,M)=CC(J,M)-QUO1*CC(I,M)
   13 W(J)=W(J)-QUO1*W(I)
      IF (CC(N,N) NE 0.) GO TO 15
      GO TO 203
   15 K(N)=W(N)/CC(N,N)
      I=N-1
   16 SUM=0
      IPLUS1=I+1
      DO 17 J=IPLUS1,N
   17 SUM=SUM+CC(I,J)*K(J)
      K(I)=(W(I)-SUM)/CC(I,I)
      I=I-1
      IF (I GT 0) GO TO 16
  202 WRITE (9,201)(K(I),I=1,N)
  201 FORMAT (/,' CORRELATES ',/,3(D18 9,/),/)
      GO TO 205
  203 WRITE (9,201)
  204 FORMAT (' ***ERROR***==>IN CORRELATE MATRIX')
      GO TO 999
  205 CONTINUE
      SUMVV=0
      DO 121 I=1,N
  121 SUMVV=SUMVV+K(I)*WW(I)*1 0D12
C***  THIS SECTION COMPUTES THE CORRECTIONS TO EACH LINE IN MILLIMETERS
      IF (NTYPE EQ 3) GO TO 130
      VAB=K(N)*PAB/KAB*10**6
      VBC=K(N)*PBC/KBC*10**6
      VCD=K(N)*PCD/KCD*10**6
      VAD=K(N)*PAD/KAD*10**6
      IF (NTYPE EQ 1) VAC=K(N)*PAC/KAC*10**6
      IF (NTYPE EQ 1) VBD=K(N)*PBD/KBD*10**6
      IF (NTYPE NE 2) GO TO 130
      VAE=K(N)*PAE/KAE*10**6
      VBE=K(N)*PBE/KBE*10**6
      VCE=K(N)*PCE/KCE*10**6
      VDE=K(N)*PDE/KDE*10**6
  130 CONTINUE
      IF (NTYPE NE 3) GO TO 126
      VAB=PAB*(K(1)/KAB+K(2)/KAB2)*10**6
      VBC=PBC*(K(1)/KBC+K(2)/KBC2+K(3)/KBC3)*10**6
      VCD=PCD*(K(1)/KCD+K(3)/KCD3)*10**6
      VAD=PAD*K(1)/KAD*10**6
      VAC=PAC*(K(1)/KAC+K(2)/KAC2)*10**6
      VBD=PBD*(K(1)/KBD+K(3)/KBD3)*10**6
      VAE=PAE*K(2)/KAE2*10**6
      VBE=PBE*(K(2)/KBE2+K(3)/KBE3)*10**6
      VCE=PCE*(K(2)/KCE2+K(3)/KCE3)*10**6
      VDE=PDE*K(3)/KDE3*10**6
  126 CONTINUE
      WRITE (9,127) VAB,VBC,VCD,VAD
  127 FORMAT (' CORRECTIONS TO LINES (MM) ',/,' VAB=',F7 1,/,' VBC=',F7
     1 1,/,' VCD=',F7 1,/,' VAD=',F7 1)
      IF (NTYPE NE 2) WRITE (9,128) VAC,VBD
  128 FORMAT (' VAC=',F7 1,/,' VBD=',F7 1)
      IF (NTYPE NE 1) WRITE (9,129) VAE,VBE,VCE,VDE
  129 FORMAT (' VAE=',F7 1,/,' VBE=',F7 1,/,' VCE=',F7 1,/,' VDE=',F7 1)
C***  THIS SECTION COMPUTES A CHECK ON SUM VV, USING THE LINE LENGTH
C***  CORRECTIONS, AND WRITES SUM VV, THE CHECK ON SUM VV, AND SIGMA
      SUMVV2=VAB**2/PAB+VBC**2/PBC+VCD**2/PCD+VAD**2/PAD
      IF (NTYPE NE 2) SUMVV2=SUMVV2+VAC**2/PAC+VBD**2/PBD
      IF (NTYPE NE 1) SUMVV2=SUMVV2+VAE**2/PAE+VBE**2/PBE+VCE**2/PCE+V
     1DE**2/PDE
```

```
      AMU=DSQRT(SUMVV2/N)
      WRITE (9,138) SUMVV,SUMVV2,AMU
  138 FORMAT (/,' SUM VV=',F9.3,/,' CHECK ON SUM VV=',F9.3,/,' SIGMA=',F
     17.3,' MM/LINE')
C***  THIS SECTION ADDS THE CORRECTIONS TO EACH LINE
      AB=AB+VAB*1.0D-6
      BC=BC+VBC*1.0D-6
      CD=CD+VCD*1.0D-6
      AD=AD+VAD*1.0D-6
      IF (NTYPE.NE.2) AC=AC+VAC*1.0D-6
      IF (NTYPE.NE.2) BD=BD+VBD*1.0D-6
      IF (NTYPE.EQ.1) GO TO 134
      AE=AE+VAE*1.0D-6
      BE=BE+VBE*1.0D-6
      CE=CE+VCE*1.0D-6
      DE=DE+VDE*1.0D-6
  134 CONTINUE
      WRITE (9,135) AB,BC,CD,AD
  135 FORMAT (/,' ADJUSTED LINE LENGTHS (KM) ',/,' AB=',F10.6,/,' BC=',F
     110.6,/,' CD=',F10.6,/,' AD=',F10.6)
      IF (NTYPE.NE.2) WRITE (9,136) AC,BD
  136 FORMAT (' AC=',F10.6,/,' BD=',F10.6)
      IF (NTYPE.NE.1) WRITE (9,137) AE,BE,CE,DE
  137 FORMAT (' AE=',F10.6,/,' BE=',F10.6,/,' CE=',F10.6,/,' DE=',F10.6)
C***  THIS SECTION COMPUTES A CHECK ON THE LINE LENGTH CORRECTIONS
      CLOS=(VAB/KAB+VBC/KBC+VCD/KCD+VAD/KAD)*1.0D-6
      IF (NTYPE.NE.2) CLOS=CLOS+(VAC/KAC+VBD/KBD)*1.0D-6
      IF (NTYPE.EQ.2) CLOS=CLOS+(VAE/KAE+VBE/KBE+VCE/KCE+VDE/KDE)*1.0D-6
      CLOSE(1)=CLOS-W(1)
      IF (NTYPE.NE.3) GO TO 141
      CLOS=(VAB/KAB2+VBC/KBC2+VAC/KAC2+VAE/KAE2+VBE/KBE2+VCE/KCE2)*1.D-6
      CLOSE(2)=CLOS-W(2)
      CLOS=(VBC/KBC3+VCD/KCD3+VBD/KBD3+VBE/KBE3+VCE/KCE3+VDE/KDE3)*1.D-6
      CLOSE(3)=CLOS-W(3)
  141 CONTINUE
      WRITE (9,139)
  139 FORMAT (/,' CHECK OF CORRECTIONS ')
      WRITE (9,140) (I,CLOSE(I),I=1,N)
  140 FORMAT (I3,' ',D12.5)
C***  THIS SECTION GOES BACK AND RECOMPUTES EACH ANGLE, AND THE CONDI-
C***  TION RESIDUALS AFTER ADJUSTMENT
      NO=1
      GO TO 104
  144 CONTINUE
C***  THIS SECTION COMPUTES THE TRIANGLE CLOSURES AFTER ADJUSTMENT
      IF (NTYPE.EQ.2) GO TO 145
      Z(1)=(AQ(1,1)+AQ(1,2)+AQ(1,3)+AQ(1,4)-360.)*3600
      Z(2)=(AQ(3,3)+AQ(2,4)-AQ(2,2)-AQ(3,1))*3600
      Z(3)=(AQ(2,3)+AQ(3,2)-AQ(3,4)-AQ(2,1))*3600.
  145 CONTINUE
      IF (NTYPE.EQ.1) GO TO 146
      Z(4)=(AQ(6,1)+AQ(6,2)+AQ(6,3)+AQ(6,4)-360.)*3600
      Z(5)=(AQ(5,1)+AQ(5,2)+AQ(5,3)+AQ(5,4)+AQ(4,1)+AQ(4,2)+AQ(4,3)+AQ(4
     1,4)-360.)*3600
  146 CONTINUE
      WRITE (9,147)
  147 FORMAT (/,' TRIANGLE CONDITION CLOSURES ')
      II=4
      IF (NTYPE.NE.2) II=1
      LL=5
      IF (NTYPE.EQ.1) LL=3
      WRITE (9,148) (Z(I),I=II,LL)
  148 FORMAT (F9.3,'"')
  999 STOP
```

```
      END
C***  FUNCTION ANGLE COMPUTES AN ANGLE, GIVEN THREE LINE LENGTHS BY
C***  USING THE COSINE LAW
      FUNCTION ANGLE(X,Y,Z)
      DOUBLE PRECISION X,Y,Z,DACOS
      ANGLE=DACOS((X**2+Y**2-Z**2)/(2.*X*Y))
      RETURN
      END
C***  FUNCTIONS KORM1, KORM2, AND KORM3 COMPUTE NORMALS TO THE LINES.
      FUNCTION KORM1(V,W,X,Y,Z)
      DOUBLE PRECISION V,W,X,Y,Z,DCOS,DSIN
      KORM1=1.D0/((W*DCOS(Y)-V)/(V*W*DSIN(Y))+(X*DCOS(Z)-V)/(V*X*DSIN(Z)
     1))
      RETURN
      END
      FUNCTION KORM2(T,U,V,W,X,Y,Z)
      DOUBLE PRECISION T,U,V,W,X,Y,Z,DSIN
      KORM2=1.D0/(T/(U*V*DSIN(W))+T/(X*Y*DSIN(Z)))
      RETURN
      END
      FUNCTION KORM3(W,X,Y,Z)
      DOUBLE PRECISION W,X,Y,Z,DSIN
      KORM3=1.D0/(W/(X*Y*DSIN(Z)))
      RETURN
      END
C***  FUNCTION WEIGHT COMPUTES THE WEIGHT OF A LINE, GIVEN ITS LENGTH,
C***  USING A DESIRED WEIGHTING FUNCTION
      FUNCTION WEIGHT(D)
      DOUBLE PRECISION D
      WEIGHT=D/D
      RETURN
      END
```

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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C        PROGRAM TO COMPUTE HTM PLANE, GEOGRAPHICAL, AND USR COORDIN-  C
C     ATES OF A POINT, WRITTEN BY BRUCE SCHENCK, APRIL, 1978.          C
C                                                                      C
C        PROGRAM COMPUTES PLANE COORDINATES OF UNKNOWN POINT FROM      C
C     BASELINE OF TWO KNOWN POINTS AND DISTANCES FROM EACH OF THESE    C
C     POINTS TO UNKNOWN POINT. IF ONLY ONE POINT OF BASELINE IS KNOWN, C
C     APPROXMATE COORDINATES OF SECOND BASELINE POINT ARE SUPPLIED,    C
C     AND THE AZIMUTH OF THE BASELINE IS COMPUTED. BY USING THIS AZI-  C
C     MUTH AND THE KNOWN DISTANCE, EXACT COORDINATES OF THE SECOND     C
C     BASELINE POINT IN THE SYSTEM ARE COMPUTED, AND THE PROGRAM PRO-  C
C     CEEDS BY USING THESE COORDINATES                                 C
C        INPUT TO PROGRAM IS AS FOLLOWS                                C
C        CARD #1  HEADER CARD WHICH WILL BE PRINTED AT TOP OF OUTPUT   C
C        CARD #2  COLS   1-16, BASE POINT #1                           C
C                 COLS  17-32, BASE POINT #2                           C
C                 COLS  33-48; UNKNOWN POINT                           C
C        CARD #3  COL    7, "NTYPE", IF NTYPE=1, COORDINATES OF BASE   C
C     POINT #2 ARE APPROXIMATE, IF NTYPE=2, COORDINATES OF BASE POINT  C
C     #2 ARE KNOWN, AND WILL NOT BE COMPUTED                           C
C                 COL   16, "ISIGNY", + IF UNKNOWN POINT IS ABOVE BASE- C
C     LINE, - IF UNKNOWN POINT IS BELOW BASELINE                       C
C        CARD #4  COLS   1-10, "DBL", HTM PLANE DISTANCE FROM BASE     C
C     POINT #1 TO BASE POINT #2, F10.3                                 C
C                 COLS  11-20, "XB1", HTM PLANE X COORDINATE OF BASE   C
C     POINT #1, F10.3                                                  C
C                 COLS  21-30, "YB1", HTM PLANE Y COORDINATE OF BASE   C
C     POINT #1, F10.3                                                  C
C                 COLS  31-40, "XB2", HTM PLANE X COORDINATE OF BASE   C
C     POINT #2, F10.3                                                  C
C                 COLS  41-50, "YB2", HTM PLANE Y COORDINATE OF BASE   C
C     POINT #2, F10.3                                                  C
C        CARD #5  COLS   1-10, "DB1P", HTM PLANE DISTANCE FROM BASE    C
C     POINT #1 TO UNKNOWN POINT, F10.3.                                C
C                 COLS  11-20, "DB2P", HTM PLANE DISTANCE FROM BASE    C
C     POINT #2 TO UNKNOWN POINT, F10.3                                 C
C        CARD #6  COLS  1-3, "ICMDEG", LONGITUDE (DEG.) OF CENTRAL     C
C     MERIDIAN OF ZONE, I3                                             C
C                 COLS  5-6, "ICMMIN", LONGITUDE (MIN.) OF CENTRAL     C
C     MERIDIAN OF ZONE, I2                                             C
C                 COLS  8-9, "ICMSEC", LONGITUDE (SEC.) OF CENTRAL     C
C     MERIDIAN OF ZONE, I2                                             C
C                 COLS  11-20, "OFFSET", X COORDINATE IN METERS OF     C
C     CENTRAL MERIDIAN OF ZONE, F10.3                                  C
C        CARD #7  COLS   1- 8, "H(1)", ELEVATION IN METERS OF BASE     C
C     POINT #1, F8.3                                                   C
C                 COLS   9-16, "H(2)", ELEVATION IN METERS OF BASE     C
C     POINT #2, F8.3                                                   C
C                 COLS  17-24, "H(3)", ELEVATION IN METERS OF UNKNOWN  C
C     POINT, F8.3                                                      C
C        OUTPUT CONSISTS OF THE FOLLOWING:                             C
C          1  THE HEADER                                               C
C          2  THE BASELINE USED IN THE COMPUTATIONS                    C
C          3  THE HTM PLANE DISTANCES INPUT TO THE PROGRAM             C
C          4  THE X & Y PLANE COORDINATES OF EACH POINT                C
C          5  THE GEOGRAPHICAL COORDINATES OF EACH POINT               C
C          6  THE CURVATURE RADIUS OF THE PRIME VERTICAL               C
C          7  THE USR COORDINATES OF EACH POINT                        C
C          8  THE SPATIAL CHORD DISTANCES BETWEEN EACH PAIR OF POINTS  C
C     CALCULATED FROM THE USR COORDINATES OF EACH POINT                C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
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C***  THIS SECTION INITIALIZES VARIABLES AND READS INPUT
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION XA(20),POINT(4),BASE1(4),BASE2(4),H(3)
      DATA XDIFF/10.0D-31/,A/6378206.4D0/,E2/0.006768658D0/
      DATA IYPOS/'+'/,IYNEG/'-'/
      PI=3.1415926535898D00
      E4=E2**2
      E6=E2**6
      READ (8,100) XA
  100 FORMAT (20A4)
      WRITE (9,100) XA
      READ (8,111) BASE1,BASE2,POINT
  111 FORMAT (4A4,4A4,4A4)
      READ (8,106) NTYPE,ISIGNY
  106 FORMAT (I7,I1,T16,A1)
      READ (8,107) DBL,XB1,YB1,XB2,YB2
  107 FORMAT (5F10.3)
      READ (8,108) DB1P,DB2P
  108 FORMAT (2F10.3)
      READ (8,101) ICMDEG,ICMMIN,ICMSEC,OFFSET
  101 FORMAT (I3,1X,I2,1X,I2,1X,F10.3)
      READ (8,113) H(1),H(2),H(3)
  113 FORMAT (3F8.3)
      WRITE (9,119) BASE1,BASE2
  119 FORMAT (' BASE LINE FOR COMPUTATIONS IS',4A4,'TO',4A4)
      WRITE (9,130) BASE1,BASE2,DBL,BASE1,POINT,DB1P,BASE2,POINT,DB2P
  130 FORMAT (/,' HIM PLANE DISTANCES (M) ',/,4A4,'TO',4A4,'=',F10.3,/,4
     1A4,'TO',4A4,'=',F10.3,/,4A4,'TO',4A4,'=',F10.3)
C***  THIS SECTION COMPUTES THE X & Y PLANE COORDINATES OF BASE POINT #2.
      DXX=XB2-XB1
      DYY=YB2-YB1
      IF (NTYPE .EQ. 2) GO TO 109
      AZBASE=DATAN(DXX/DYY)
      IF (AZBASE .LT. 0.) AZBASE=AZBASE+PI
      XB2=XB1+DBL*DSIN(AZBASE)
      YB2=YB1+DBL*DCOS(AZBASE)
      DXX=XB2-XB1
      DYY=YB2-YB1
  109 CONTINUE
      WRITE (9,117)
  117 FORMAT (/,' COORDINATES ON HIM PLANE')
      WRITE (9,118) BASE1,XB1,BASE1,YB1,BASE2,XB2,BASE2,YB2
  118 FORMAT (' ''X'' COORDINATE OF',4A4,'=',F12.3,/,' ''Y'' COORDINATE
     1OF',4A4,'=',F12.3,/,' ''X'' COORDINATE OF',4A4,'=',F12.3,/,' ''Y''
     2 COORDINATE OF',4A4,'=',F12.3)
C***  THIS SECTION COMPUTES THE PLANE COORDINATES OF THE UNKNOWN POINT.
      XPP=(DB1P**2-DB2P**2+DBL**2)/(2.*DBL)
      YPP=DSQRT(DB1P**2-XPP**2)
      IF (ISIGNY .EQ. IYNEG) YPP=-YPP
      X3=XB1+XPP*DXX/DBL-YPP*DYY/DBL
      Y3=YB1+XPP*DYY/DBL+YPP*DXX/DBL
      WRITE (9,110) POINT,X3,POINT,Y3
  110 FORMAT (' ''X'' COORDINATE OF',4A4,'=',F12.3,/,' ''Y'' COORDINATE
     1OF',4A4,'=',F12.3)
C***  THIS LOOP COMPUTES GEOGRAPHICAL AND USR COORDINATES FOR EACH POINT.
      DO 116 J=1,3
      IF (J .EQ. 1) XXX=XB1
      IF (J .EQ. 1) YYY=YB1
      IF (J .EQ. 2) XXX=XB2
      IF (J .EQ. 2) YYY=YB2
      IF (J .EQ. 3) XXX=X3
      IF (J .EQ. 3) YYY=Y3
C***  THIS SECTION INITIALIZES VARIABLES USED IN THE ITERATION PROCESS.
      CMER=PI/180.*(ICMDEG+ICMMIN/60.+ICMSEC/3600.)
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```
      DX=XXX-OFFSET
      CL=(YYY/0.99996666667D0+2249134.918D0)/A
      C1=1.D0-0.25D0*E2-3.D0/64.D0*E4-5.D0/256.D0*E6
      C2=3.D0/8.D0*E2+3.D0/32.D0*E4+45.D0/1024.D0*E6
      C3=15.D0/256.D0*E4+45.D0/1024.D0*E6
      C4=35.D0/3072.D0*E6
      PHI=CL/C1
      I=0
C***  THIS SECTION IS THE ITERATION LOOP TO FIND PHI', THE FOOTPOINT LATITUDE.
  102 CONTINUE
      I=I+1
      CORR=-C2*DSIN(2.*PHI)+C3*DSIN(4.*PHI)-C4*DSIN(6.*PHI)
      CL1=CL-CORR
      RHI=CL1/C1
      DIFF=DABS(RHI-PHI)
      PHI=RHI
      IF (DIFF.LE.XDIFF) GO TO 103
      GO TO 102
  103 CONTINUE
C***  THIS SECTION COMPUTES THE GEOGRAPHICAL COORDINATES, PHI & LAMDA.
      W=DSQRT(1.D0-E2*DSIN(PHI)**2)
      AM=A*(1.-E2)/W**3
      AN=A/W
      DLAMDA=DX/(AN*DCOS(PHI)*0.99996666667D0)-(1.D0/(6.*AN**3*DCOS(PHI)
     1))*(1.+2.*DTAN(PHI)**2)*(DX/0.99996666667D0)**3
      PHI=PHI-DTAN(PHI)/(2.*AM*AN)*(DX/0.99996666667D0)**2+DTAN(PHI)/(24
     1.*AM*AN**3)*(5.+3.*DTAN(PHI)**2)*(DX/0.99996666667D0)**4
      DEG=PHI*180./PI
      IDEG=IDINT(DEG)
      AMIN=(DEG-IDEG)*60.
      IMIN=IDINT(AMIN)
      SEC=(AMIN-IMIN)*60
      ALAMDA=CMER-DLAMDA
      DEG=ALAMDA*180./PI
      IDEG1=IDINT(DEG)
      AMIN=(DEG-IDEG1)*60
      IMIN1=IDINT(AMIN)
      SEC1=(AMIN-IMIN1)*60
      IF (J.EQ.1) WRITE (9,112) BASE1
      IF (J.EQ.2) WRITE (9,112) BASE2
      IF (J.EQ.3) WRITE (9,112) POINT
  112 FORMAT (/,' GEOGRAPHICAL COORDINATES OF',4A4)
      IF (J.EQ.3) WRITE (9,104) I
  104 FORMAT (' NUMBER OF ITERATIONS TO FIND PHI'' ',I8)
      WRITE (9,105) PHI,IDEG,IMIN,SEC,ALAMDA,IDEG1,IMIN1,SEC1
  105 FORMAT (' PHI   (RADIANS)=',D17.11,3X,'PHI   (DEG ,MIN ,SEC )=',I4
     1,1X,I2,1X,F8.5,/,' LAMDA (RADIANS)=',D17.11,3X,'LAMDA (DEG ,MIN.,S
     2EC )=',I4,1X,I2,1X,F8.5)
C***  THIS SECTION COMPUTES THE USR COORDINATES
      W=DSQRT(1.D0-E2*DSIN(PHI)**2)
      AN=A/W
      X=(AN+H(J))*DCOS(PHI)*DCOS(ALAMDA)
      Y=-(AN+H(J))*DCOS(PHI)*DSIN(ALAMDA)
      Z=(AN*(1.-E2)+H(J))*DSIN(PHI)
      IF (J.EQ.1) AN1=AN
      IF (J.EQ.2) AN2=AN
      IF (J.EQ.1) XXB1=X
      IF (J.EQ.1) YYB1=Y
      IF (J.EQ.1) ZZB1=Z
      IF (J.EQ.2) XXB2=X
      IF (J.EQ.2) YYB2=Y
      IF (J.EQ.2) ZZB2=Z
  116 CONTINUE
      WRITE (9,114) BASE1,AN1,XXB1,YYB1,ZZB1
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      WRITE (9,114) BASE2,AN2,XXB2,YYB2,ZZB2
      WRITE (9,114) POINT,AN,X,Y,Z
  114 FORMAT (/,' UNIVERSAL SPACE RECTANGULAR COORDINATES OF',4A4,/,' CU
     1RVATURE RADIUS OF PRIME VERTICAL, N=',F13.3,/,' X=',F13.3,/,' Y=',
     2F13.3,/,' Z=',F13.3)
C**   THIS SECTION COMPUTES THE SPATIAL CHORD DISTANCE BETWEEN EACH PAIR
C**   OF POINTS FROM THE USR COORDINATES OF EACH POINT
      DDXX=XXB1-XXB2
      DDYY=YYB1-YYB2
      DDZZ=ZZB1-ZZB2
      DDXX1=X-XXB1
      DDYY1=Y-YYB1
      DDZZ1=Z-ZZB1
      DDXX2=X-XXB2
      DDYY2=Y-YYB2
      DDZZ2=Z-ZZB2
      DIBL=DSQRT(DDXX**2+DDYY**2+DDZZ**2)
      DIB1P=DSQRT(DDXX1**2+DDYY1**2+DDZZ1**2)
      DIB2P=DSQRT(DDXX2**2+DDYY2**2+DDZZ2**2)
      WRITE (9,115) BASE1,BASE2,DIBL,BASE1,POINT,DIB1P,BASE2,POINT,DIB2P
  115 FORMAT (/,' SPATIAL CHORD DISTANCE OF',4A4,''TO',4A4,'=',F10.3,/,'
     1SPATIAL CHORD DISTANCE OF',4A4,'TO',4A4,'=',F10.3,/,' SPATIAL CHOR
     2D DISTANCE OF',4A4,'TO',4A4,'=',F10.3)
  999 STOP
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C         PROGRAM TO MAKE A SPATIAL INTERSECTION AND COMPUTE THE LAT-  C
C     TITUDE, LONGITUDE, AND ELEVATION OF THE POINT IN QUESTION        C
C     WRITTEN BY BRUCE SCHENCK, MARCH 1978                             C
C                                                                      C
C         PROGRAM TAKES THE UNIVERSAL SPACE RECTANGULAR COORDINATES OF C
C     KNOWN POINTS, ALONG WITH THE APPROXIMATE COORDINATES OF THE      C
C     POINT IN QUESTION, AND USES AN ITERATIVE PROCESS TO SOLVE FOR    C
C     THE USR COORDINATES OF THE UNKNOWN POINT. THESE COORDINATES,     C
C     ALONG WITH AN APPROXIMATE LATITUDE AND CURVATURE RADIUS IN THE   C
C     PRIME VERTICAL, ARE THEN USED TO COMPUTE THE LATITUDE, LONGI-    C
C     TUDE, AND ELEVATION OF THE POINT                                 C
C         INPUT CARD FORMATS ARE AS FOLLOWS                            C
C         CARD #1  HEADER CARD WHICH WILL BE PRINTED AT TOP OF OUTPUT  C
C         CARD #2  COLS  3-4, "N", NUMBER OF KNOWN POINTS INPUT, I2    C
C         CARD #3-#N+2. COLS  1-10, DISTANCE IN KM FROM KNOWN POINT TO C
C     UNKNOWN POINT, F10.6. COLS  11-40, X, Y, Z COORDINATES OF KNOWN  C
C     POINT, 3F13.6                                                    C
C         CARD #N+3  COLS. 11-40, APPROXIMATE X, Y, Z COORDINATES OF   C
C     UNKOWN POINT, 3F13.6                                             C
C         CARD #N+4  COLS  1-12; "RN", RADIUS IN PRIME VERTICAL, F12.6 C
C     COLS  14-15, APPROXIMATE LATITUDE (DEG.) OF UNKNOWN POINT, I2    C
C     COLS  17-18; APPROXIMATE LATITUDE (MIN.) OF UNKNOWN POINT, I2    C
C     COLS. 20-26, APPROXIMATE LATITUDE (SEC.) OF UNKNOWN POINT, F7.4  C
C         OUTPUT CONSISTS OF HEADER ON CARD #1, X, Y, Z COORDINATES    C
C     CALCULATED BY NEXT TO LAST ITERATION, X, Y, Z COORDINATES CALCU- C
C     LATED BY LAST ITERATION, NUMBER OF ITERATIONS PERFORMED, LATI-   C
C     TUDE, LONGITUDE, AND ELEVATIONS OF POINT CALCULATED FROM EACH OF C
C     THE THREE COORDINATES                                            C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C***  THIS SECTION INITIALIZES VARIABLES AND READS INPUT
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION D(5),X(5),Y(5),Z(5),XX(20),Q(5),W(5),CC(5,5)
      NN=0
      MM=0
      PI=3.1415926535898D00
      READ (8,101) XX
  101 FORMAT (20A4)
      READ (8,102) N
  102 FORMAT (2X,I2)
      READ (8,100) (D(I),X(I),Y(I),Z(I),I=1,N)
  100 FORMAT (F10.6,3F13.6)
      WRITE (9,101) XX
      READ (8,108) XBAR,YBAR,ZBAR
  108 FORMAT (T11,3F13.6)
C***  THIS SECTION SETS UP X, Y, Z MATRIX
  103 CONTINUE
      DO 104 I=1,N
  104 W(I)=((X(I)-XBAR)*X(I)+(Y(I)-YBAR)*Y(I)+(Z(I)-ZBAR)*Z(I))-D(I)**2
      DO 105 I=1,N
  105 CC(I,1)=(X(I)-XBAR)
      DO 106 I=1,N
  106 CC(I,2)=(Y(I)-YBAR)
      DO 107 I=1,N
  107 CC(I,3)=(Z(I)-ZBAR)
C*** THIS SECTION CONSISTS OF A GAUSSIAN ELIMINATION PROCESS TO SOLVE
C*** THE MATRIX FOR X, Y, Z
      IF(N.NE.1) GO TO 4
      IF(CC(1,1).EQ.0.) GO TO 3
      Q(1)=W(1)/CC(1,1)
      GO TO 202
```

```
      3 GO TO 203
      4 NLESS1=N-1
        DO 13 I=1,NLESS1
        BIG=ABS(CC(I,I))
        L=I
        IPLUS1=I+1
        DO 6 J=IPLUS1,N
        IF (ABS(CC(J,I))  LE  BIG) GO TO 6
        BIG=ABS(CC(J,I))
        L=J
      6 CONTINUE
        IF (BIG  NE. 0.) GO TO 8
        GO TO 203
      8 IF (L .EQ  I) GO TO 11
        DO 10 J=1,N
        TEMP=CC(L,J)
        CC(L,J)=CC(I,J)
     10 CC(I,J)=TEMP
        TEMP=W(L)
        W(L)=W(I)
        W(I)=TEMP
     11 DO 13 J=IPLUS1,N
        QUOT=CC(J,I)/CC(I,I)
        DO 12 M=IPLUS1,N
     12 CC(J,M)=CC(J,M)-QUOT*CC(I,M)
     13 W(J)=W(J)-QUOT*W(I)
        IF (CC(N,N) .NE. 0.) GO TO 15
        GO TO 203
     15 Q(N)=W(N)/CC(N,N)
        I=N-1
     16 SUM=0
        IPLUS1=I+1
        DO 17 J=IPLUS1,N
     17 SUM=SUM+CC(I,J)*Q(J)
        Q(I)=(W(I)-SUM)/CC(I,I)
        I=I-1
        IF (I  GT  0) GO TO 16
    202 CONTINUE
    201 FORMAT (/,' COORDINATES ',/,' X=',F15.7,/,' Y=',F15 7,/,' Z=',F15.
       17,/)
        GO TO 205
    203 WRITE (9,204)
    204 FORMAT (' ***ERROR***==>IN CORRELATE MATRIX')
        GO TO 999
C***    THIS SECTION CHECKS IF THE UNKNOWN X, Y, Z HAVE CONVERGED  IF NOT
C***    DO ITERATION AGAIN, OTHERWISE GO ON
    205 CONTINUE
        IF (NN  EQ  1) GO TO 899
        IF (ABS(Q(1)-XBAR)  LT. 0 0000001  AND  ABS(Q(2)-YBAR)  LT  0 0000
       1001  AND  ABS(Q(3)-ZBAR)  LT  0.0000001)  NN=1
        IF (MM  GT  1000) NN=1
        IF (NN  EQ  1) WRITE (9,201) (Q(I),I=1,N)
        MM=MM+1
        XBAR=(Q(1)+XBAR)/2.
        YBAR=(Q(2)+YBAR)/2
        ZBAR=(Q(3)+ZBAR)/2.
        GO TO 103
    899 WRITE (9,201) (Q(I),I=1,N)
        WRITE (9,120) MM
    120 FORMAT (' NUMBER OF ITERATIONS.',I5)
        READ (8,110) RN,IDEG,IMIN,SEC
    110 FORMAT (F12 6,1X,I2,1X,I2,1X,F7 4)
C***    THIS SECTION COMPUTES PHI, LAMDA, AND THE ELEVATIONS FROM EACH OF
C***    THE COORDINATES
```

```
      PHI=(SEC/3600 +IMIN/60 +IDEG)*PI/180
      ALAMDA=DATAN2(Q(1),Q(2))
      HBAR=Q(1)/(DCOS(PHI)*DSIN(ALAMDA))-RN
      PHI=DATAN(((6378.2064D0+HBAR)/(6356.5838D0+HBAR))**2*Q(3)*DSIN(ALA
     1MDA)/Q(1))
      HX=(Q(1)/(DCOS(PHI)*DSIN(ALAMDA)))-RN
      HY=(Q(2)/(DCOS(PHI)*DCOS(ALAMDA)))-RN
      HZ=(Q(3)/DSIN(PHI))-(RN*(6356.5838D0**2/6378.2064D0**2))
      PHI=PHI*180./PI
      IDEG=INT(PHI)
      AMIN=(PHI-IDEG)*60.
      IMIN=INT(AMIN)
      SEC=(AMIN-IMIN)*60
      ALAMDA=ALAMDA*180./PI
      IDEG1=INT(ALAMDA)
      AMIN=(ALAMDA-IDEG1)*60
      IMIN1=INT(AMIN)
      SEC1=(AMIN-IMIN1)*60
      WRITE (9,111) IDEG,IMIN,SEC,IDEG1,IMIN1,SEC1,HX,HY,HZ
  111 FORMAT (' PHI=',1X,I2,1X,I2,1X,F6.3,5X,'LAMDA=',1X,I3,1X,I2,1X,F6.
     13,/,' COMPUTED ELEVATIONS.',/,' H(X)=',F10.6,' KM   H(Y)=',F10.6,'
     2 KM   H(Z)=',F10.6,' KM')
  999 STOP
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C          PROGRAM TO COMPUTE THE ELLIPSOIDAL ARC DISTANCE GIVEN THE   C
C      LATITUDE AND LONGITUDE OF TWO TERMINAL POINTS.  WRITTEN BY      C
C      BRUCE SCHENCK, APRIL 1978.                                      C
C                                                                      C
C          INPUT TO THE PROGRAM CONSISTS OF THREE CARDS FOR EACH LINE  C
C      LENGTH CALCULATED. THE FIRST CARD OF EACH SET IS A HEADER CARD. C
C      THE CONTENTS OF THIS CARD WILL BE PRINTED BEFORE THE CALCULATED C
C      LINE LENGTH IN THE OUTPUT. THE SECOND CARD OF EACH SET CONTAINS C
C      THE LATITUDES OF THE TERMINAL POINTS IN DEGREES, MINUTES, AND   C
C      SECONDS, IN AN I3,1X,I2,1X,F8.5,1X,I3,1X,I2,1X,F8.5 FORMAT. THE C
C      THIRD CARD OF EACH SET CONTAINS THE LONGITUDES OF THE TERMINAL  C
C      POINTS IN THE SAME FORMAT AS THE LATITUDES. THE THIRD CARD OF   C
C      THE FINAL SET DATA SHOULD BE FOLLOWED BY A BLANK CARD.          C
C          OUTPUT CONSISTS OF EACH HEADER, FOLLOWED BY EACH CALCULATED  C
C      ELLIPSOIDAL ARC DISTANCE                                        C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION XX(20),LATDEG(2),LATMIN(2),SECLAT(2),LONDEG(2),LONMIN(2)
     1,SECLON(2),PHI(2),W(2),AN(2),ALAMDA(2)
      DATA RM/6362.0D0/,PI/3.141592653589BD0/,E2/0.006768658D0/,A/6378.2
     1064D0/
  110 CONTINUE
      READ (8,100) XX
  100 FORMAT (20A4)
      WRITE (9,100) XX
      READ (8,101) (LATDEG(I),LATMIN(I),SECLAT(I),I=1,2)
      READ (8,101) (LONDEG(I),LONMIN(I),SECLON(I),I=1,2)
  101 FORMAT (2(I3,1X,I2,1X,F8.5,1X))
      DO 102 I=1,2
      PHI(I)=(SECLAT(I)/3600.+LATMIN(I)/60.+LATDEG(I))*PI/180.
      ALAMDA(I)=(SECLON(I)/3600.+LONMIN(I)/60.+LONDEG(I))*PI/180.
      IF (PHI(1).EQ.0.0.AND.ALAMDA(1).EQ.0.0) GO TO 999
      W(I)=DSQRT(1.D0-E2*DSIN(PHI(I))**2)
      AN(I)=A/W(I)
  102 CONTINUE
      DLAMDA=DABS(ALAMDA(1)-ALAMDA(2))
      DC=DSQRT(4.D0*AN(1)*AN(2)*DCOS(PHI(1))*DCOS(PHI(2))*DSIN(DLAMDA/2.
     1)**2+(AN(1)*DCOS(PHI(1))-AN(2)*DCOS(PHI(2)))**2+(1.-E2)**2*(AN(1)*
     2DSIN(PHI(1))-AN(2)*DSIN(PHI(2)))**2)
      DA=DC+DC**3/(24.*RM**2)
      WRITE (9,103) DA
  103 FORMAT (' ELLIPSIODAL DISTANCE =',F10.6,' KM')
      GO TO 110
  999 STOP
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C        PROGRAM TO COMPUTE REFRACTIVE NUMBER OF ATMOSPHERE;           C
C     WRITTEN BY BRUCE SCHENCK, OCTOBER 1977                           C
C                                                                      C
C        THIS PROGRAM COMPUTES THE REFRACTIVE NUMBERS, N, OF THE       C
C     ATMOSPHERE AT POINTS OF MEASURED TEMPERATURE, BAROMETRIC         C
C     PRESSURE, AND HUMIDITY. THE PROGRAM THEN GOES AHEAD WITH A LEAST C
C     SQUARES METHOD TO MAKE A POLYNOMIAL MODEL OF THE ATMOSPHERE, AND C
C     THEN COMPUTES THE MEAN REFRACTIVE NUMBER OF THE ATMOSPHERE BE-   C
C     TWEEN THE ENDPOINTS.  THE STANDARD ERROR OF A MEASUREMENT IS ALSO C
C     COMPUTED AT THIS TIME.  THE LAST PART OF THE PROGRAM COMPUTES    C
C     WEIGHT AND CORRELATION NUMBERS OF THE POLYNOMIAL COEFFICIENTS    C
C     FROM THESE NUMBERS THE STANDARD ERROR OF THE FUNCTION IS COM-    C
C     PUTED.  ALL COMPUTATIONS ARE DONE IN DOUBLE PRECISION.  THE PRO- C
C     GRAM STARTS BY SOLVING FOR A POLYNOMIAL WITH THREE UNKNOWNS, AND C
C     KEEPS LOOPING THROUGH A POLYNOMIAL WITH 20 UNKNOWNS              C
C        THE FIRST DATA CARD IS A HEADER UPON WHICH ANY INFORMATION    C
C     CAN BE SUPPLIED TO BE PRINTED AT THE TOP OF EACH SECTION OF OUT- C
C     PUT. THE SECOND DATA CARD CONTAINS "NINPUT" IN COLUMN #8         C
C     "NINPUT" TELLS THE PROGRAM WHAT KIND OF INPUT DATA WILL BE SUP-  C
C     PLIED.  NINPUT=1 INDICATES THAT THE INPUT DATA CONSISTS OF ALTI- C
C     TUDES AND PREVIOUSLY COMPUTED REFRACTIVE NUMBERS FOR EACH        C
C     ALTITUDE. NINPUT=2 INDICATES THAT THE INPUT DATA CONSISTS OF AL- C
C     TITUDES, DRY BULB TEMPERATURES, BAROMETRIC PRESSURES, AND WET    C
C     BULB TEMPERATURES. THE THIRD DATA CARD CONTAINS "NO" IN COLUMNS  C
C     1-3.  "NO" IS THE NUMBER OF OBSERVED ATMOSPHERIC POINTS, AND CAN C
C     TAKE ON ANY VALUE THROUGH 200.  THE REST OF THE DATA CARDS CON-  C
C     TAIN THE OBSERVED ATMOSPHERIC DATA. IF NINPUT=1 COLS  1-7 CON-   C
C     TAIN THE ALTITUDES, H IN KM., IN AN F7.0 FORMAT, COLS  8-15 CON- C
C     TAIN THE REFRACTIVE NUMBERS, EN, FOR EACH POINT IN AN F8.0       C
C     FORMAT.  IF NINPUT=2 COLS. 1-7 CONTAIN THE ALTITUDES IN AN F7.0  C
C     FORMAT, COLS  9-12 CONTAIN DRY BULB TEMPERATURES, TD IN DEG. C,  C
C     IN AN F4.0 FORMAT, COLS  14-20 CONTAIN BAROMETRIC PRESSURES, PR  C
C     IN MILLIBARS, IN AN F7.0 FORMAT, COLS  22-25 CONTAIN WET BULB    C
C     TEMPERATURES, TW IN DEG. C, IN AN F4.0 FORMAT                    C
C        THE OUTPUT CONSISTS OF THE HEADER FROM DATA CARD #1 AT THE    C
C     TOP OF EACH SECTION, FOLLOWED BY "N", THE NUMBER OF UNKNOWNS IN  C
C     THE POLYNOMIAL IN THAT SECTION.  NEXT IN THE OUTPUT IS THE POLY- C
C     NOMIAL UNKNOWNS THAT WERE SOLVED FOR, FOLLOWED BY THE ALTITUDES, C
C     OBSERVED REFRACTIVE NUMBERS, REFRACTIVE NUMBERS CALCULATED FROM  C
C     THE POLYNOMIAL, AND THE RESIDUALS, N,OBS-N,ABCDF    T  THE FINAL C
C     PART OF EACH SECTION OF THE OUTPUT IS MADE UP OF THE SUM OF THE  C
C     SQUARES OF THE RESIDUALS, SUM VV, THE STANDARD ERROR OF ONE MEA- C
C     SUREMENT, MU, THE MEAN REFRACTIVE NUMBER, NBAR, THE QUANTITY,    C
C     SUMNN, AND THE STANDARD ERROR OF THE FUNCTION, SIGMA NBAR        C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C***  THIS SECTION INITIALIZES SOME VARIABLES AND READS THE INPUT
      DIMENSION XLINE(12)
      DOUBLE PRECISION DSQRT,DEL,H(200),EN(200),D(20,20),Q(20),
     1W(20),TEMP,QUOT,BIG,SUM,ENBAR(200),V,AAMU,VV(200),BAR,H2,H1,DIF
     2,E(20),WA,CN,CA,SUMNN,AMNN,F(20,20),Z(20),T(20),HH(20),WI(20
     3),Y(210),WW(20),AK,B(20),TD(200),PR(200),TW(200),EP(200),EPM(200)
      NLIMIT=20
      N=3
      READ (8,199) (XLINE(I),I=1,12)
  199 FORMAT (12A6)
      READ (8,161) NINPUT
  161 FORMAT (7X,I1)
      READ (8,160) NO
  160 FORMAT (I3)
```

```
      IF (NINPUT .EQ. 2) GO TO 162
      READ (8,100) (H( I),EN( I), I=1,NO)
  100 FORMAT (T12,F7.0,T43,F5.0)
      GO TO 666
  162 READ (8,163) (H( I),TD( I),PR( I),TW( I), I=1,NO)
  163 FORMAT (F7.0,1X,F4.0,1X,F7.0,1X,F4.0)
C***  THIS SECTION COMPUTES N FROM OBSERVED TEMPERATURES AND PRESSURES
C***  USING THE FOLLOWING FORMULAS:
C***    E'=7.04623+0.19583*T(WET)+0.031358*T(WET)**2
C***    E=E'-0.00066*(1.0+0.0015*T(WET))*P*(T(DRY)-T(WET))
C***    N=(300.2*P-41.8*E)/(3.709*T(DRY)); T(DRY) IN DEG. K
      DO 164 I=1,NO
      EPR( I)=7.04623D0+0.195831D0*TW( I)+0.031358D0*TW( I)**2
      EP( I)=EPR( I)-0.00066D0*(1.0+0.00115D0*TW( I))*PR( I)*(TD( I)-TW( I))
      TD( I)=TD( I)+273.15D0
C***  ====> NOTE <====
C***  IN THIS FORMULA 300.2 IS THE GROUP INDEX OF REFRACTION FOR A HE-NE
C***  LASER. IF A DIFFERENT WAVELENGTH RADIATION IS USED THAT COEFFI-
C***  CIENT MUST BE CHANGED ACCORDINGLY
  164 EN( I)=(300.2D0*PR( I)-41.8D0*EP( I))/(3.709D0*TD( I))
  666 CONTINUE
C***  THIS SECTION INITIALIZES MORE VARIABLES
      V=0
      DNO=DFLOAT( NO)
      U=DFLOAT( N)
      NLESS1=N-1
      WRITE (9,199) XLINE
      WRITE (9,122) N
  122 FORMAT (/,' N=',I3)
      DO 102 I=1,NLIMIT
      DO 102 J=1,NLIMIT
  102 D( I,J)=0
C***  THIS SECTION SETS UP THE NORMAL EQUATIONS MATRIX.
      D( 1,1)=DNO
      DO 501 J=2,N
      DO 501 I=1,NO
  501 D( 1,J)=D( 1,J)+H( I)**(J-1)
      DO 502 K=2,N
      DO 502 I=1,NO
  502 D(K,N)=D(K,N)+H( I)**(K+N-2)
      DO 500 I=1,NLESS1
      DO 500 J=2,N
  500 D( I+1,J-1)=D( I,J)
      DLL=0
      DO 108 I=1,NO
  108 DLL=DLL+EN( I)**2
      DO 105 I=1,NLIMIT
  105 W( I)=0
      DO 503 J=1,N
      DO 503 I=1,NO
  503 W( J)=W( J)+EN( I)*H( I)**(J-1)
      DO 505 I=1,N
  505 WW( I)=W( I)
      DO 504 I=1,NLIMIT
  504 Q( I)=0
C***  THIS SECTION CONSISTS OF A GUASSIAN ELIMINATION PROCESS TO SOLVE
C***  THE NORMAL EQUATIONS MATRIX FOR THE POLYNOMIAL COEFFICIENTS
      IF (N .NE. 1) GO TO 4
      IF (D( 1,1) .EQ. 0 ) GO TO 3
      Q( 1)=W( 1)/D( 1,1)**(-1 )
      GO TO 205
    3 GO TO 203
    4 CONTINUE
      DO 13 I=1,NLESS1
```

```
      BIG=ABS(D(I,I))
      L=I
      IPLUS1=I+1
      DO 6 J=IPLUS1,N
      IF (ABS(D(J,I)) .LE  BIG) GO TO 6
      BIG=ABS(D(J,I))
      L=J
    6 CONTINUE
      IF (BIG .NE. 0 ) GO TO 8
      GO TO 203
    8 IF (L  EQ  I) GO TO 11
      DO 10 J=1,N
      TEMP=D(L,J)
      D(L,J)=D(I,J)
   10 D(I,J)=TEMP
      TEMP=W(L)
      W(L)=W(I)
      W(I)=TEMP
   11 DO 13 J=IPLUS1,N
      QUOT=D(J,I)/D(I,I)
      DO 12 K=IPLUS1,N
   12 D(J,K)=D(J,K)-QUOT*D(I,K)
   13 W(J)=W(J)-QUOT*W(I)
      IF (D(N,N) .NE. 0 ) GO TO 15
      GO TO 203
   15 Q(N)=W(N)/D(N,N)
      I=N-1
   16 SUM=0.
      IPLUS1=I+1
      DO 17 J=IPLUS1,N
   17 SUM=SUM+D(I,J)*Q(J)
      Q(I)=(W(I)-SUM)/D(I,I)
      I=I-1
      IF (I  GT. 0) GO TO 16
      GO TO 205
  203 WRITE (9,204)
  204 FORMAT ('***ERROR***==> IN CORRELATE MATRIX')
      GO TO 999
  205 WRITE (9,107) Q
  107 FORMAT (/,' A='F15 3,3X,'B=',F15.3,3X,'C=',F15.3,3X,'D=',F15.3,3X,
     1'E=',F15 3,//,' F=',F15 3,3X,'G=',F15 3,3X,'H=',F15 3,3X,'I=',F15
     23,3X,'J=',F15 3,3X,//,' K=',F15.3,3X,'L=',F15 3,3X,'M=',F15 3,3X,'
     3N=',F15 3,3X,'O=',F15 3,//,' P=',F15 3,3X,'Q=',F15 3,3X,'R=',F15.3
     4,3X,'S=',F15 3,3X,'T=',F15 3,/)
C***  THIS SECTION COMPUTES N FROM THE POLYNOMIAL AND THE RESIDUALS,
C***  N,OBS-N,ABCDE.  T
      DO 123 I=1,NO
  123 ENBAR(I)=0
      DO 120 I=1,NO
      DO 124 M=1,N
      F(M)=Q(M)*H(I)**(M-1)
  124 ENBAR(I)=ENBAR(I)+E(M)
  120 VV(I)=EN(I)-ENBAR(I)
      WRITE (9,119) (H(I),EN(I),ENBAR(I),VV(I),I=1,NO)
  119 FORMAT (' DATA.',/,'       H          N,OBS       N,ABCDE       RESIDUALS',
     1/,99(F10 5,F10.1,F10 1,F10.3,/))
C***  THIS SECTION COMPUTES SUM VV AND MU BY
C***    MU=SQRT(SUM VV/(NO-N))
      DO 117 I=1,NO
  117 V=V+(ENBAR(I)-EN(I))**2
      AAMU=DSQRT(V/(DNO-U))
      WRITE (9,116) V,AAMU
  116 FORMAT (' SUM VV (FROM DATA)=',F10 3,/,' MU (FROM DATA)=',F10 3)
C***  THIS SECTION COMPUTES NBAR BY
```

```
C***     NBAR=A+(H2**2-H1**2)/(H2-H1)*B/2 +(H2**3-H1**3)/(H2-H1)*C/3 +...
C***      . +(H2**N-H1**N)/(H2-H1)*X/N.
      H1=H(1)
      H2=H(NO)
      DIF=ABS(H2-H1)
      BAR=0
      DO 600 K=1,N
      AK=DFLOAT(K)
      B(K)=ABS(H2**K-H1**K)/DIF*Q(K)/AK
  600 BAR=BAR+B(K)
      WRITE (9,121) BAR
  121 FORMAT (' NBAR-',F8 3)
C***  THIS SECTION SETS UP THE WEIGHT AND CORRELATION NUMBERS MATRICES.
      DO 710 JK=1,N
      DO 301 I=1,N
      DO 301 J=1,N
  301 F(I,J)=0.
      F(1,1)=DNO
      DO 302 J=2,N
      DO 302 I=1,NO
  302 F(1,J)=H(I)**(J-1)+F(1,J)
      DO 303 K=2,N
      DO 303 I=1,NO
  303 F(K,N)=H(I)**(K+N-2)+F(K,N)
      DO 304 I=1,NLESS1
      DO 304 J=2,N
  304 F(I+1,J-1)=F(I,J)
      DO 309 I=1,N
      Z(I)=0
  309 T(I)=0
      T(JK)=1 D00
C***  THIS SECTION CONSISTS OF ANOTHER GAUSSIAN ELIMINATION PROCESS TO
C***  SOLVE FOR THE WEIGHT AND CORRELATION NUMBERS
      IF (N  NE  1) GO TO 54
      IF (F(1,1)  EQ  0 ) GO TO 53
      Z(1)=T(1)/F(1,1)**(-1 )
      GO TO 705
   53 GO TO 703
   54 CONTINUE
      DO 63 I=1,NLESS1
      BIC=ABS(F(I,I))
      L=I
      IPLUS1=I+1
      DO 56 J=IPLUS1,N
      IF (ABS(F(J,I))  LE  BIG) GO TO 56
      BIG=ABS(F(J,I))
      L=J
   56 CONTINUE
      IF (BIG  NE  0.) GO TO 58
      GO TO 703
   58 IF (L  EQ  I) GO TO 61
      DO 60 J-1,N
      TEMP=F(L,J)
      F(L,J)=F(I,J)
   60 F(I,J)=TEMP
      TEMP=T(I)
      T(L)=T(I)
      T(I)=TEMP
   61 DO 63 J=IPLUS1,N
      QUOT=F(J,I)/F(I,I)
      DO 62 K=IPLUS1,N
   62 F(J,K)=F(J,K)-QUOT*F(I,K)
   63 T(J)=T(J)-QUOT*T(I)
      IF (F(N,N)  NE  0 ) GO TO 65
```

```
      GO TO 703
   65 Z(N)=T(N)/F(N,N)
      I=N-1
   66 SUM=0
      IPLUS1=I+1
      DO 67 J=IPLUS1,N
   67 SUM=SUM+F(I,J)*Z(J)
      Z(I)=(T(I)-SUM)/F(I,I)
      I=I-1
      IF (I  GT  0) GO TO 66
      GO TO 705
  703 WRITE (9,204)
      GO TO 999
  705 CONTINUE
C***  THIS SECTION COMPUTES SUM NN AND SIGMA NBAR BY
C***    SIGMA NBAR=MU*SQRT(SUM NN).
      DO 709 M=JK,N
      KK=JK-1
  709 Y(M+KK*N-KK*(KK+1)/2)=Z(M)
  710 CONTINUE
      DO 311 I=1,N
  311 HH(I)=ABS(H2*I-H1*I)/DIF/I
      WA=0
      DO 312 I=1,N
      KA=I-1
      WI(I)=HH(I)**2*Y(I+KA*N-KA*(KA+1)/2)
  312 WA=WA+WI(I)
      CN=0
      DO 313 I=1,NLESS1
      KB=I-1
      MM=I+1
      DO 313 J=MM,N
      CA=2 D00*HH(I)*HH(J)*Y(J+KB*N-KB*(KB+1)/2)
  313 CN=CN+CA
      SUMNN=CN+WA
      IF (SUMNN  LT  0 0) GO TO 990
      AMNN=AAMU*DSQRT(SUMNN)
      WRITE (9,130) SUMNN,AMNN
  130 FORMAT (' SUM NN=',F10 3,/,' SIGMA NBAR=',F10 3,//)
      GO TO 992
  990 WRITE (9,991) SUMNN
  991 FORMAT (' SUM NN=',F10 3,/, ' SIGMA NBAR HAS BLOWN UP')
  992 CONTINUE
      N=N+1
      IF (N  LE  NLIMIT) GO TO 666
  999 STOP
      END
```