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A STUDY OF THE COUPLING OF ACOUSTIC ENERGY FROM THE TROPOSPHERE TO THE IONOSPHERE

Final Technical Report
Contract NAS8-21079

15 February 1969

CASE FILE
COPY

Prepared for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Huntsville, Alabama 35812

Prepared by

David G. Detert

AVCO CORPORATION
APPLIED TECHNOLOGY DIVISION
"Formerly Space Systems Division"
Environmental Sciences and Technology Directorate
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ABSTRACT

This report describes the efforts of the second twelve months of a continuing program (the first year's efforts being under Air Force sponsorship) of experimental measurements to investigate the possibility of coupling between ground level and ionospheric effects through the propagation of low frequency acoustic waves. The two tropospheric sources considered in this study are the static firing of large rocket engines at NASA/MSFC and the occurrence of local thunderstorms. The observing system consists of a network of three, short-baseline, near vertical incidence hf Doppler sounding paths near Huntsville, Alabama, each operating with three simultaneous transmission frequencies.

The report discusses the general operation of the experiment and the experimental findings relative to ionospheric dynamics phenomena caused by static test events and local meteorological disturbances.

A three-dimensional acoustic ray-tracing computer program is briefly described, and a Fortran listing is given.

ACKNOWLEDGMENT

The original inspiration for this program was generated in large measure by Samuel Coroniti, until recently of Avco/SSD. The arrangements for field site selection and usage were made by William T. Roberts of NASA/MSFC, who also served as technical monitor for the contract.

Michael Thomas of Avco/Huntsville was responsible for the installation of the two field sites established under this program, including the development of their equipments, and he directed all aspects of the subsequent operation of the four sites utilized for the measurement series. This program would not have been possible without the personal attention and effort he gave to the experiment.

Spectral processing of the recorded doppler data was carried out with facilities at the Rome Air Development Center, made available through the generosity of Major Donald Wippermann there. The personal interest of Kenneth Ford of the RADC Data Reduction Center lead to the development of substantial improvements in processing procedures; he was also responsible for the careful processing of the bulk of the records.

Charles Moo of Avco/SSD served as a willing and continuous source of advice and encouragement in this program. Barbara Willey provided all the graphics for this report, and Ethel Ouellette who patiently typed the final and numerous earlier drafts of the text.

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I. INTRODUCTION

In April of 1967 an experimental program was begun in the vicinity of Huntsville, Alabama to study coupling between ground level phenomena and ionospheric effects, concentrating specifically on perturbations produced in the ionosphere by the static firings of large rocket engines at NASA/MSFC and by local meteorological disturbances. Due to the nature of these "sources," it was assumed that any coupling which would be detected was achieved by the mechanism of vertically propagating low-frequency acoustic waves.

The basic observing technique employed in this experimental program has been remote radio sensing of the ionosphere by hf vertical incidence Doppler soundings, in which the apparent variations in the received frequency of various vertically propagated ultra-stable hf/cw radio signals are monitored at a single receiving site on the ground. The resultant Doppler shifts are related to the dynamics of the ionospheric region in which the waves are reflected. Details of this measurement approach have been given by a number of workers [1, 2, 3]. The first year of this research program was sponsored by the Rome Air Development Center, under contract F30602-67-C-0016, which called for the establishment of one near vertical incidence Doppler sounding path, over which three fixed frequencies in the range 2 to 6 MHz were continuously transmitted. Data were collected for some five months.

This report describes the results of a second year of effort in the Huntsville experimental program. The objectives of this second phase were similar to those of the first year, but the observing system was substantially expanded to include three different near vertical incidence Doppler sounding paths of differing lengths, each transmitting three simultaneous frequencies. The experiment was operated over a period of eight months, and included approximately 1000 hours of operation in which all nine signals were simultaneously present, in addition to many more hours in which a smaller number of signals were recorded. Figure 1 (a) shows the configuration of the four sites established near Huntsville, Alabama, for this phase of the program, with the relevant distances between the ionospheric reflection points and the NASA/MSFC static test stands. Figure 1 (b) shows the same map, with the distances marked between ionospheric reflection points.

The results of the first year's experimental operation have been reported elsewhere [4, 5] but can be summarized briefly as showing encouraging evidence of ionospheric perturbations being produced by several of the static rocket tests which were monitored. It appeared that the acoustic output spectra of the various tests were sufficiently similar to rule out variations in test characteristics as being the cause of the limited number of successfully detected events, and it seems likely that either the characteristics of the intervening media or the electron density configuration at the particular ionospheric reflection heights were

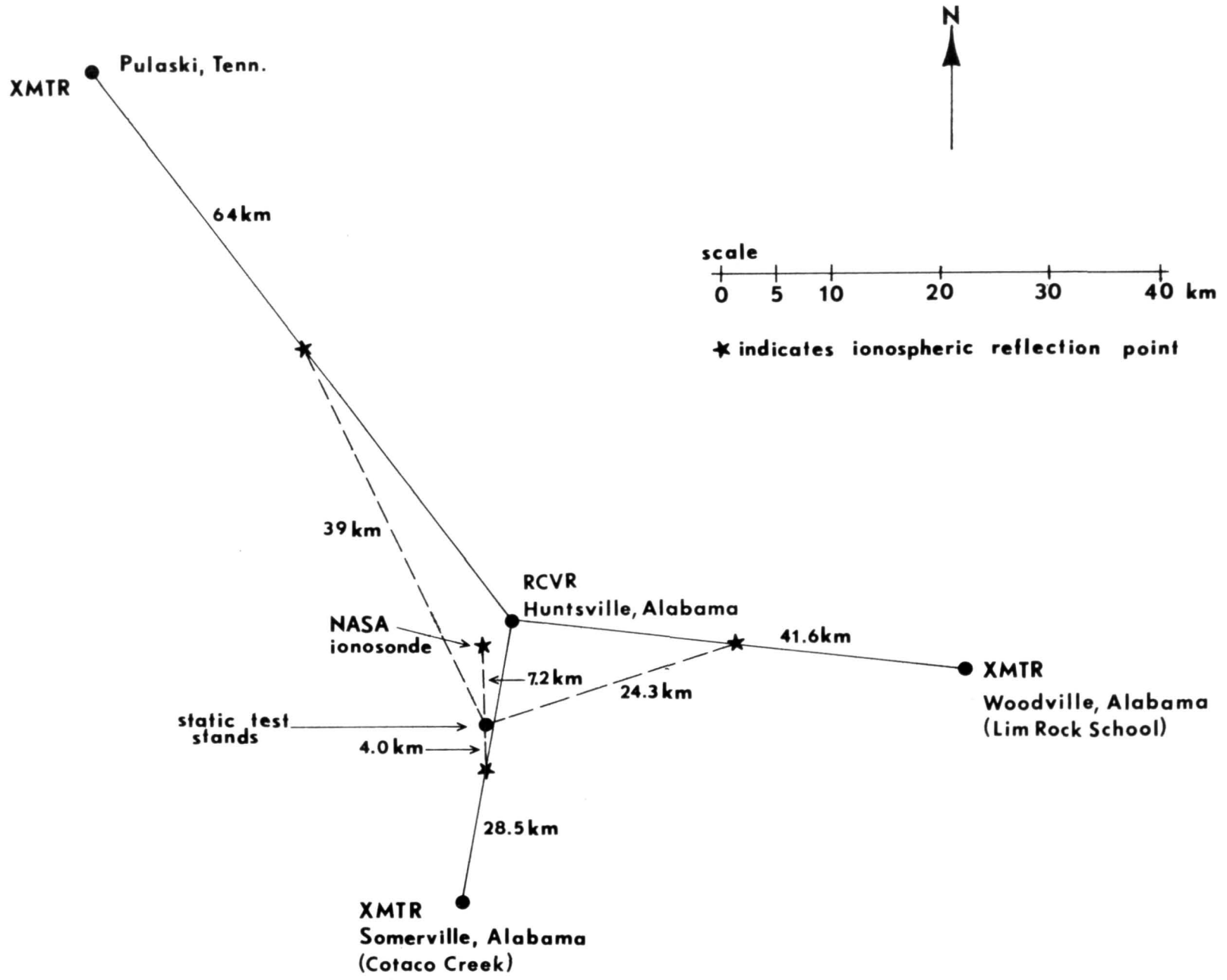


Figure 1 (a): Experimental configuration for monitoring static firings

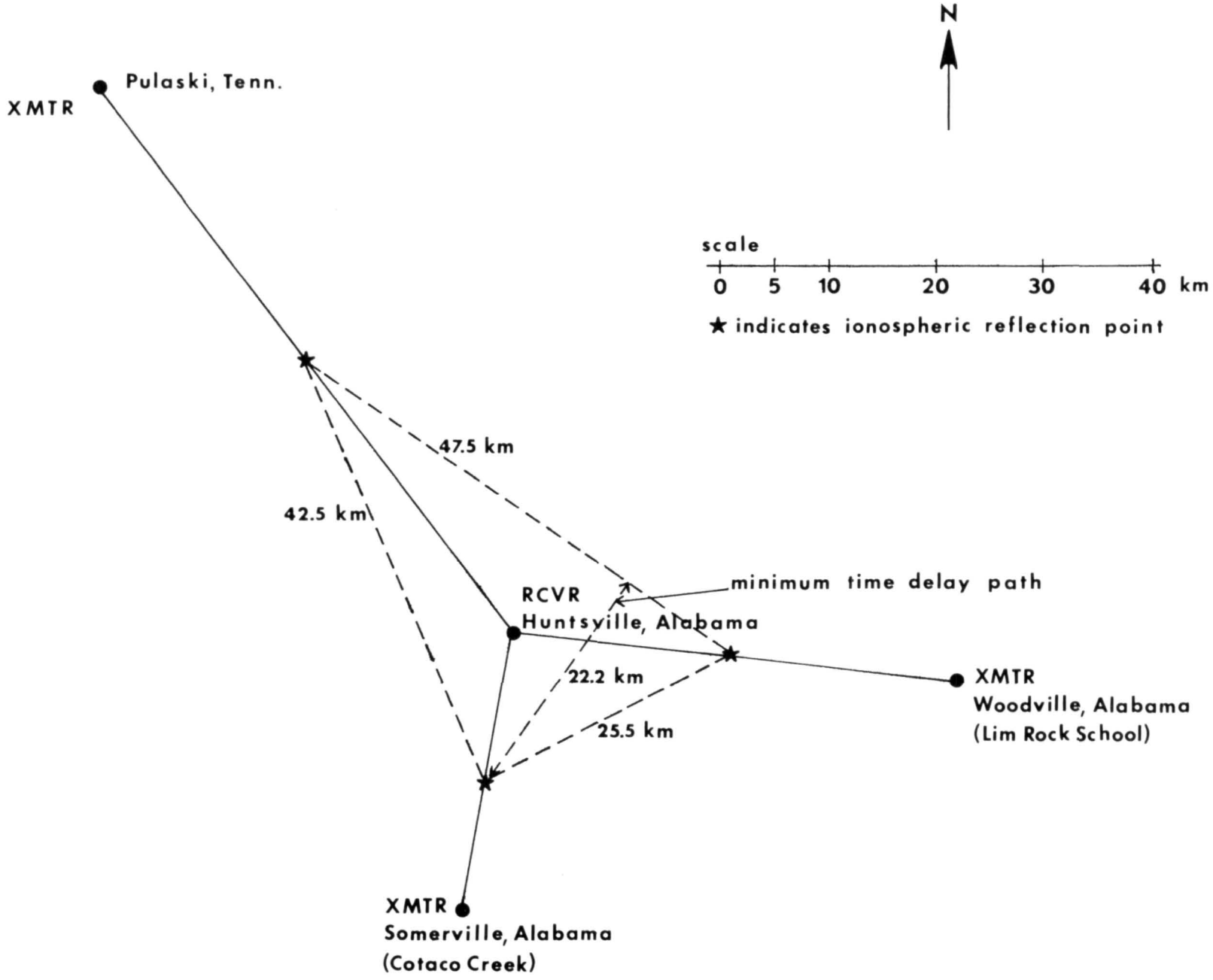


Figure 1 (b): Experimental configuration for monitoring ionospheric perturbations

therefore responsible for this aspect of the observations. The results for the case of thunderstorm induced interactions were few and inconclusive. The expected perturbations due to traveling ionospheric disturbances (TID's) and solar flares (SFD's) were observed in substantial numbers.

The intent of the second year's program was to substantially expand the observing capabilities, so that a three-dimensional, short-baseline picture could be obtained of the ionospheric perturbations which the Doppler sounding technique could observe, and to extend the Doppler data processing procedures to improve frequency resolution and optimize data presentations for different effects. The use of three frequencies over each of the three transmission paths shown in Figure 1 provided continuous monitoring of nine different points in the ionosphere at three different heights.

The results of the second year's program are the subject of this report. In addition to a summary of the experimental operations, detailed discussions of data taken during static firings, and data showing effects related to local meteorological disturbances, appendices containing a log of the data collection periods, and the Fortran listing and description of an acoustic ray-tracing program adapted for use in this study, are included.

II. EXPERIMENTAL OPERATIONS

A. EQUIPMENT

The principal equipment development effort in this program consisted of the installation of transmitter sites at the Pulaski County Airport near Pulaski, Tennessee, and at the Limrock Elementary School, located near Woodville, Alabama. At each of these sites, two 70-foot towers were erected, and three inverted vee antennas were installed: two at right angles to each other on one tower, and one on the second tower. Coaxial cables were laid and buried in the ground between the antennas and the three transmitters housed in existing buildings at both sites. Oscillator units, consisting of power supplies and individual crystal oscillators in shielded cans, were fabricated for each location.

Heathkit DX-60A transmitters were employed, but they proved to be difficult to maintain in continuous operation for long periods of time. Utilizing certain suggestions made by John E. Jones of ITSA/Boulder in this regard, and after some additional troubleshooting by Michael Thomas of Avco/Huntsville, they were modified as described in Appendix A. These changes proved to be adequate for continuous operation for periods of the order of weeks. Several Viking Valiant transmitters were also placed into service during the program as replacements for the Heathkits, and these proved to be more easily adapted to the required mode of operation as well as considerably more reliable.

Frequency allocations available for this experiment were 6.185, 5.735, 4.760, 4.081, 2.732, and 1.9985 MHz. At the Cotaco Creek site, the transmitters and oscillators were set to operate at any three of these frequencies, designated here as f_1, f_2, and f_3. At the Limrock site, the transmitters were operated at $f_1 + \Delta$, $f_2 + \Delta$, and $f_3 + \Delta$, while at the Pulaski site they were operated at $f_1 - \Delta$, $f_2 - \Delta$, and $f_3 - \Delta$. Values of Δ ranged from 10 Hz to 2 Hz, the latter value being adopted in the later portion of the program when it became apparent that this provided adequate separation between signals for all except the most drastic Doppler variations. In this format, a single receiver at the Avco/Huntsville receiving site, tuned to frequency f_1, actually received three signals, all of which were recorded together on a single track of the magnetic tape recorder. The three transmissions clustered about each frequency were not resolved into separate signals until the spectral analysis process, where frequency resolutions of the order of tenths of a Hertz were sufficient to display the independent variations of each transmission. Also in the latter portion of the program a 30 second break in all the recorded data was placed at the beginning of each hour, and this proved to be the simplest and least

confusing method of depositing a permanent time reference on each of the three data channels.

Figure 2 shows a typical 24-hour sequence of Doppler records taken with the Cotaco transmissions only, for three different frequencies during February 15-16, 1968. A log of all the data collection periods in the operation of this experiment is given in Appendix B.

Two microbarographs of the type developed by Claerbout[6] were built and placed at the Limrock and Pulaski sites, to be operated together with a similar unit built under the earlier RADC program. Several months of data were taken successfully with the RADC microbarograph, which was operated at the Cotaco site and later at the Avco/Huntsville plant. Approximately a month of data was collected with the microbarograph at the Limrock site. Considerable difficulties were encountered with the ink-type strip chart recorders during unattended field operation, and this proved to be the limiting factor in the amount of data collected at the Limrock site as well as the total cause of the fact that no data of any significance was recorded at the Pulaski site.

A narrowband electronic filter was built with an effective bandwidth of 2 Hz, to be used for separation of the three clustered signals at each experiment frequency when conducting spectral analysis of the recorded data at a playback speedup factor of 64 times. This is required for amplitude variation analysis of the individual transmissions, and is easily positioned in frequency over the signal of interest during the processing sequence.

B. DOPPLER DATA RECORDING AND PROCESSING

It developed that the Ampex FR-1107 tape recorder being used to record Doppler data on magnetic tape at the Avco/Huntsville receiving site was capable of operation at two slower speeds than the previously employed 15/16 ips. Either 15/32 or 15/64 ips could be achieved by replacing the existing capstan drive shaft with one having 1/4 the circumference, a standard item available from Ampex. This was done, producing the following three significant improvements in recording and processing procedures:

(a) One 10-inch reel of magnetic tape covered approximately 49 hours of data, instead of the previous 12 1/4 hours, and the receiving equipment required proportionately less attention for continuous operation.

(b) Spectral processing at the same playback speed utilized before--60 ips--increased the effective frequency resolution by a factor of

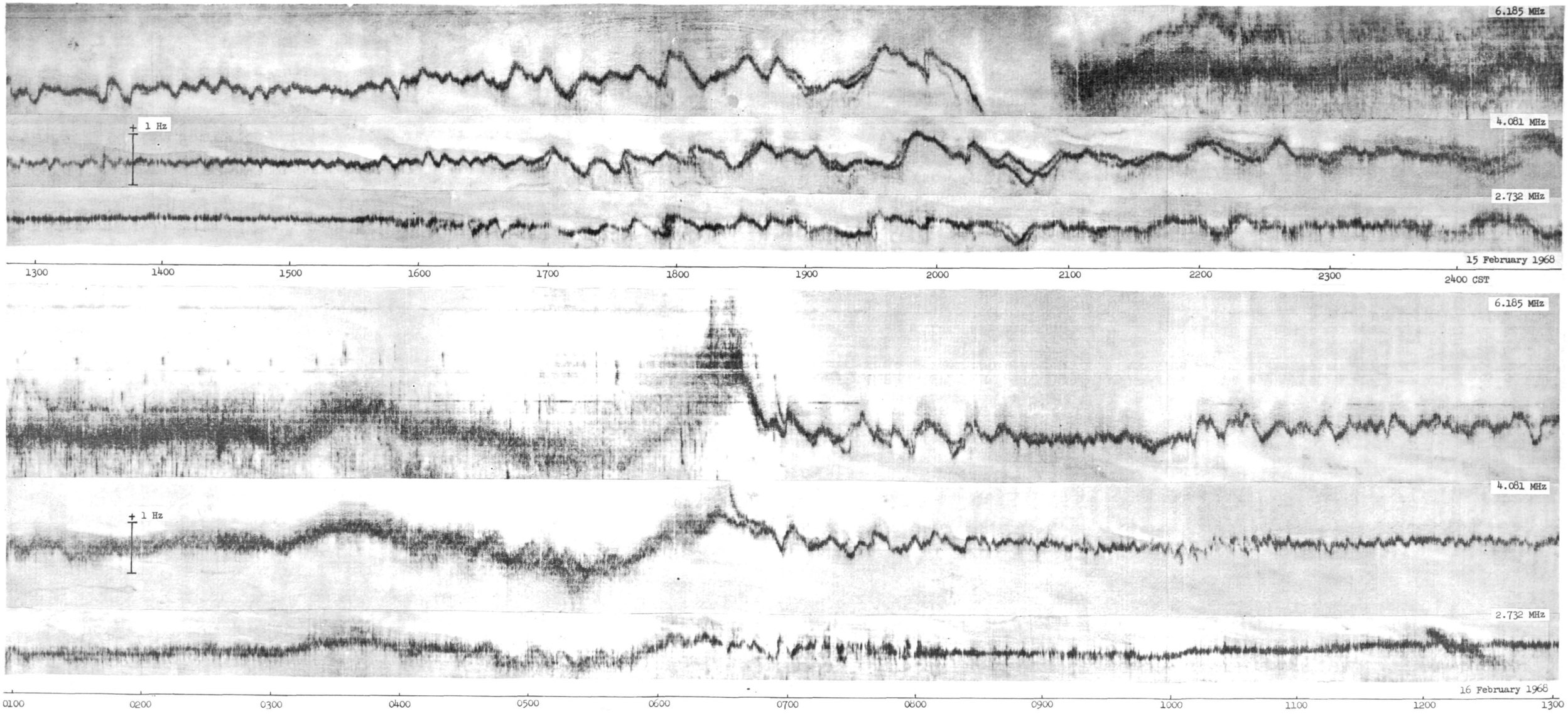


Figure 2: Typical Doppler data record,
15-16 February 1968; Huntsville, Alabama

four, and expanded the frequency scale of the analyzer output (in terms of the Hertz/inch of the resultant spectral record) by the same amount, regardless of the processor involved. This change aided substantially in identifying small Doppler deviations in the recorded data.

(c) Spectral processing time for routine analysis was reduced by a factor of four over that previously required for the same period of data recording.

The only apparent disadvantage of this approach was that the output of the spectrum analyzers is then compressed in time by a factor of four. This has proven to be beneficial in identifying longer-period Doppler variations, however, and could of course be eliminated by slowing the tape playback speed anytime fine time resolution is required.

It became apparent that achieving the same increase in resolution and expansion of the output display for the older data recorded at 15/16 ips would aid tremendously in its analysis also, so it was arranged to re-record selected earlier tapes in a fashion which would allow further effective speedup in the analysis process. It was then possible to process any of the data tapes at several different speedup factors, with the resolutions and processing times shown in Table 1 for the two most commonly used RADC DRC analyzers.

C. RADAR OBSERVATIONS OF STATIC TEST SHOCKS

One of the features of static tests which seems to be important in consideration of possible resultant ionospheric effects is the propagation of the shock wave generated by the explosive onset of the engine burn. It was suggested by Dr. Gideon Kantor at Avco/SSD that the work of Allen and Weiner[7] with the EMAC probe concept might be applicable in this context. They examined in detail the possibility of utilizing radar returns from acoustic shock fronts to measure wind velocity, turbulence, and air temperature--the so-called electromagnetic acoustic probing technique.

Previous tests of this concept performed by the Midwest Research Institute were severely limited in observable range by the high acoustic frequency used in the experiment (about 20 KHz). Instead of radar reflections from an acoustic multiple wave train, Allen and Weiner proposed reflections from a single acoustic shock front by coherent integration of the pulsed Doppler radar signal. They suggested propagating an acoustic shock wave generated by a single sinusoidal half-wave pulse whose wavelength corresponds to approximately 100 Hz or lower. At the time of their study, no

TABLE 1. SPECTRAL ANALYSIS PARAMETERS

RADC Data Reduction Center

Playback Speedup Factor	Wideband Rayspan				Narrowband Rayspan				Processing Time per data channel	
	Frequency Resolution	Frequency Width of Display	Displayed Hertz per Record Inch	Displayed inches/hour	Frequency Resolution	Frequency Width of Display	Displayed Hertz per Record Inch	Displayed Inches/hour	15/16 ips Recording	15/64 ips Recording
64	3/8 Hz	60 Hz	7.8	8	1/6 Hz	20 Hz	2.6	10 3/4	12 minutes	48 minutes
128	3/16	30	3.9	4	1/12	10	1.3	5 3/8	6	24
256	3/32	15	1.95	2	1/24	5	.65	2 3/4	3	12

such source at significant power levels was available, but the large static tests at MSFC provide both a shock wave at ignition and tremendous energies at the frequency range of interest.

The 15 second firing of an S1B engine on January 25 was monitored using the 3 cm wavelength CPS-9 weather radar available at the MSFC meteorological station, but without any positive results. A second attempt to observe the static test shock, using the MSFC weather radar and the ESSA 10 cm installation at the Madison County Airport, was also unsuccessful.

In their report discussing the problem of obtaining observable radar echoes from shock fronts, Allen and Weiner indicate that the two most crucial factors are the range at which observation is attempted and the electromagnetic wavelength of the radar. In an example which they compute for an FPS-20 radar (23 cm wavelength and 5000 kw peak power output), it is estimated that the maximum range for observation, assuming conditions of low atmospheric attenuation and with no turbulence or steady transverse winds, is approximately five miles. The presence of turbulence decreases the range limit significantly, and transverse winds reduce it drastically. On the matter of wavelength, they demonstrate theoretically that the radar wavelength should be longer than the transverse thickness of the shock front being probed. It is not clear at present what thicknesses are typical for static tests shocks, but for sonic booms the thickness appears to be on the order of 1-20 cm[8, 9].

Applying these facts to the static test situation, it seems possible that the MSFC weather radar may operate at too high a frequency (3.2 cm), and it seems likely that the ESSA radar is too far distant (approximately 10 miles with 60 kw) even though its frequency is more appropriate (10 cm). Allen and Weiner had also suggested that coherent detection techniques be employed to enhance observation of any moving fronts, and neither radar employed here had that capability.

III. STATIC TEST RESULTS

One of the prime initial motivations of the Huntsville experimental Doppler sounding program, and the aspect of the study which has been the subject of the principal effort to date, is the idea that the release of energy during the static firing of a large rocket engine on the ground might be sufficiently great to produce a measurable perturbation in the ionosphere, at least directly overhead the location of the test. The results of several other earlier experiments encouraged this. In 1966 Marcos [10] reported that it was possible to generate an ionospheric perturbation, detectable with vertical incidence Doppler sounding techniques, by flying a supersonic aircraft in a trajectory which focused the resultant shock front at a point in the upper atmosphere. In the same year, Barry, Griffiths, and Taenzer [11] reported that substantial, predictable ionospheric perturbations were observed by vertical incidence phase sounders following the explosion of 500 tons of TNT at ground level. So the possibility of low frequency waves propagating upwards into the ionosphere from a source with sufficient energy at the requisite frequencies was clearly established.

During the course of the first phase of this program, the fact that several static tests firings had previously been monitored elsewhere for the purpose of detecting possible ionospheric effects came to light. The details of these tests and their effects were described in an earlier report [5], but the essence of these results is repeated here for the sake of completeness. In the winter of 1964-65 Stanford Research Institute personnel monitored three static firings of solid fuel, one million pound thrust engines, near San Francisco, California, using a vertical incidence swept-frequency ionosonde located 48.5 km from the test stand [12]. In each case clear evidence of Sporadic-E-like traces appeared following tests, at frequencies considerably higher than any background Sporadic-E otherwise observed. The onset times of this phenomenon varied considerably, and will be discussed in more detail below. For two of these tests, fixed frequency vertical incidence phase path sounders were also operated on several frequencies at varying distances from the test stand, and positive indications of ionospheric perturbations were obtained in the resultant phase records, although the details of these variations have not been reported. In February 1966 a vertical incidence ITT phase sounder was operated at four frequencies during the static firing of a 3.6 million pound thrust, solid fuel engine near Miami, Florida. Notable perturbations appeared in the phase data on all four frequencies, and unusual and significant Sporadic-E-like echoes were also observed in the records, which were taken some 60 km from the test stand.

With these results in mind, the Doppler records taken during 30 static rocket engine tests at NASA/MSFC have been processed and analyzed in detail in an

attempt to identify ionospheric perturbations associated with the ground level firings. The particular booster engines involved are the F1, the S1B, and the S1C, with 1.5 million, 1.6 million, and 7.5 million pounds of thrust, respectively. It was decided, on the basis of considerable experimenting with various frequency and time scales for presenting the Doppler records, that the output of the narrowband Rayspan analyzer at a speedup factor of 128 times was the most useful for analysis of static test period data, representing an expanded frequency scale without excessive time compression of the data, and this processing format was utilized to produce the uniform set of static test Doppler records presented in Appendix C.

Thirteen of the test records show secondary traces which can be considered as being possibly due to vertically propagating wave motions generated by the static tests. For ease of analysis the candidate signal traces have been extracted from these thirteen cases and reproduced in Figures 3 through 6, with approximately 50 minutes of record being given in each case from the time of onset of the test. A great deal of consideration and visual analysis of the data records has gone into the selection of these candidate effects. Most of the data sequences were spectrally analyzed a number of times with differing processing gains in an attempt to positively identify the existence of any small amplitude secondary traces which may have been present. An illustration of this process is found in Figures 40 (b) - (d) in Appendix C, in which the same segment of data is reprocessed with three different gain settings. The candidate traces selected from these figures are shown in the 10 May 1968 case in Figure 6. Since, as is evident after even a cursory review of the data presented in Appendix C, any effects which may be associated with the static tests are of the same or smaller Doppler deviation magnitude than the perturbations which occur naturally on the Doppler records, and since they may also be of smaller signal intensity, the selection process leading to the data presented in Figures 3-6 is necessarily subjective and based on the analyst's experience with vertical incidence Doppler data and his educated judgment of what the various signal traces and their variations represent.

With these qualifying statements in mind, it is useful to consider the common characteristics present in the secondary traces shown in Figures 3-6, in an attempt to consider what they may indicate collectively concerning their relationship (if any) to the static firings which they follow. First, the frequency shifts of the candidate traces show a negative Doppler deviation, which is what should occur for perturbations moving away from the observer. Second, the secondary traces can be conveniently grouped into three classes: (a) those which begin with a large negative deviation with respect to the main signal trace, and then show a decreasing amount of negative Doppler with time until they merge with the main trace; (b) those which begin at the main signal trace and show with time an increasing amount of negative Doppler deviation with respect to the main signal; and (c) those which are never connected with the

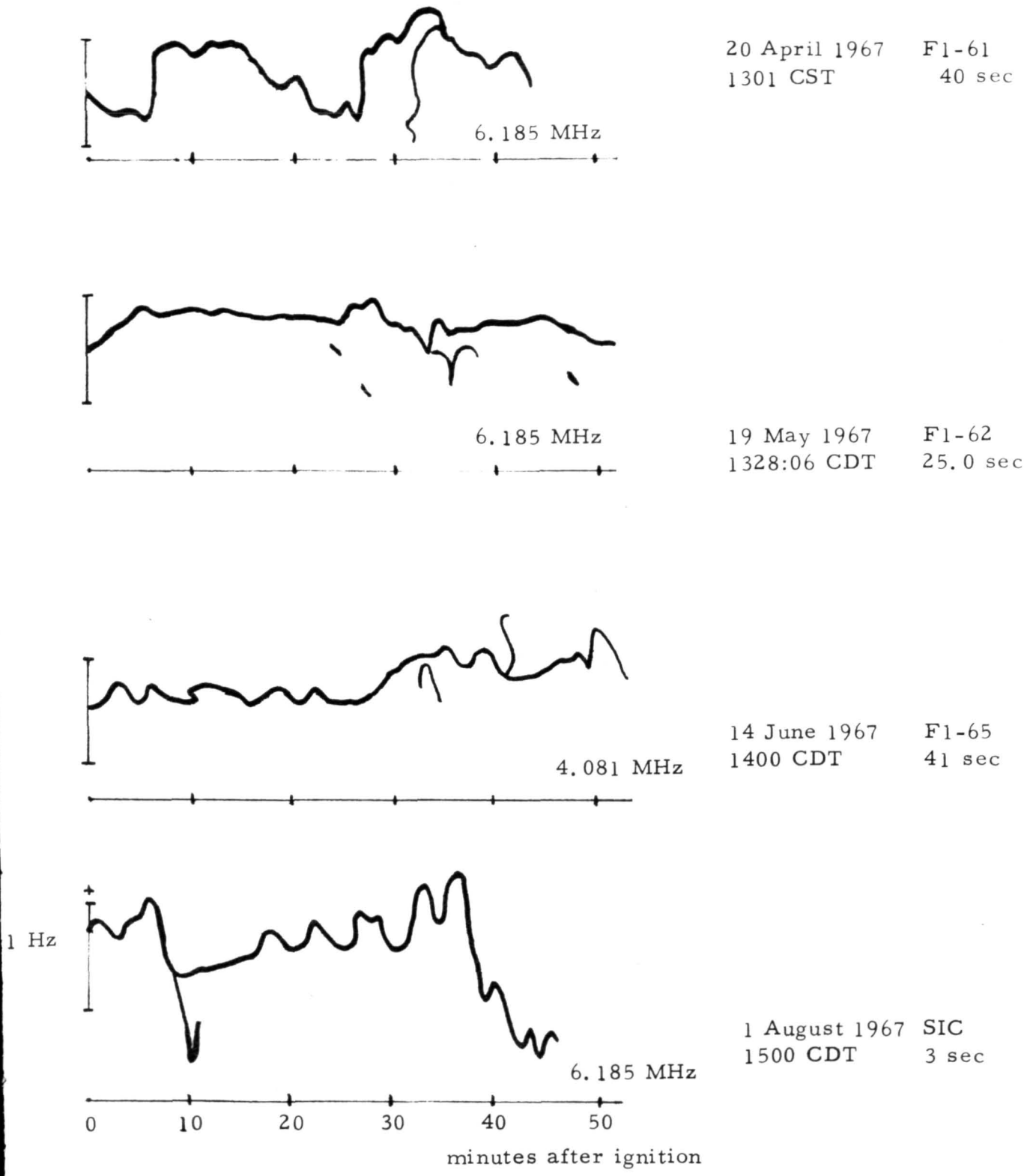


Figure 3: Tracings of Doppler data records, showing effects due to MSFC static rocket tests

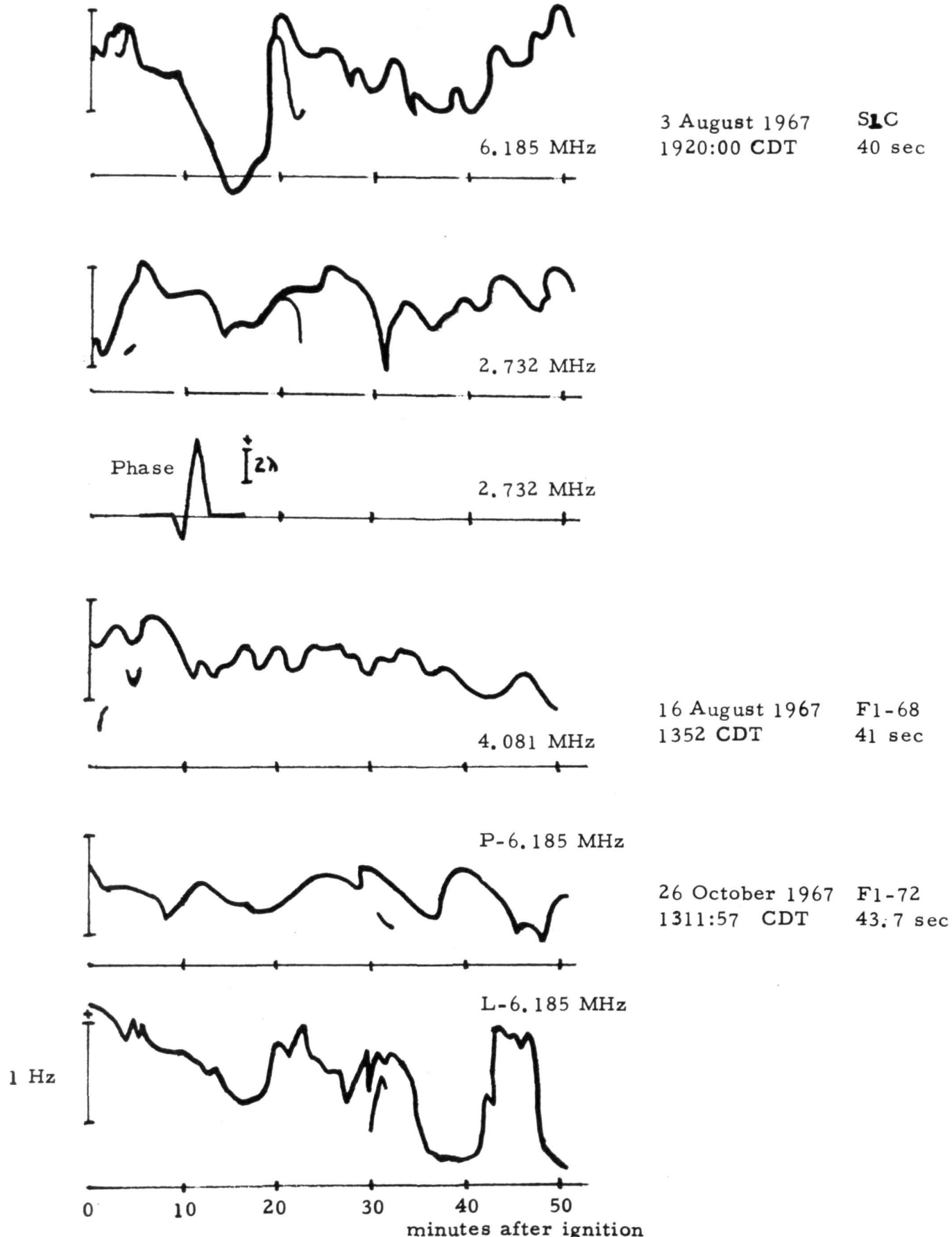


Figure 4: Tracings of Doppler data records, showing effects due to MSFC static rocket tests

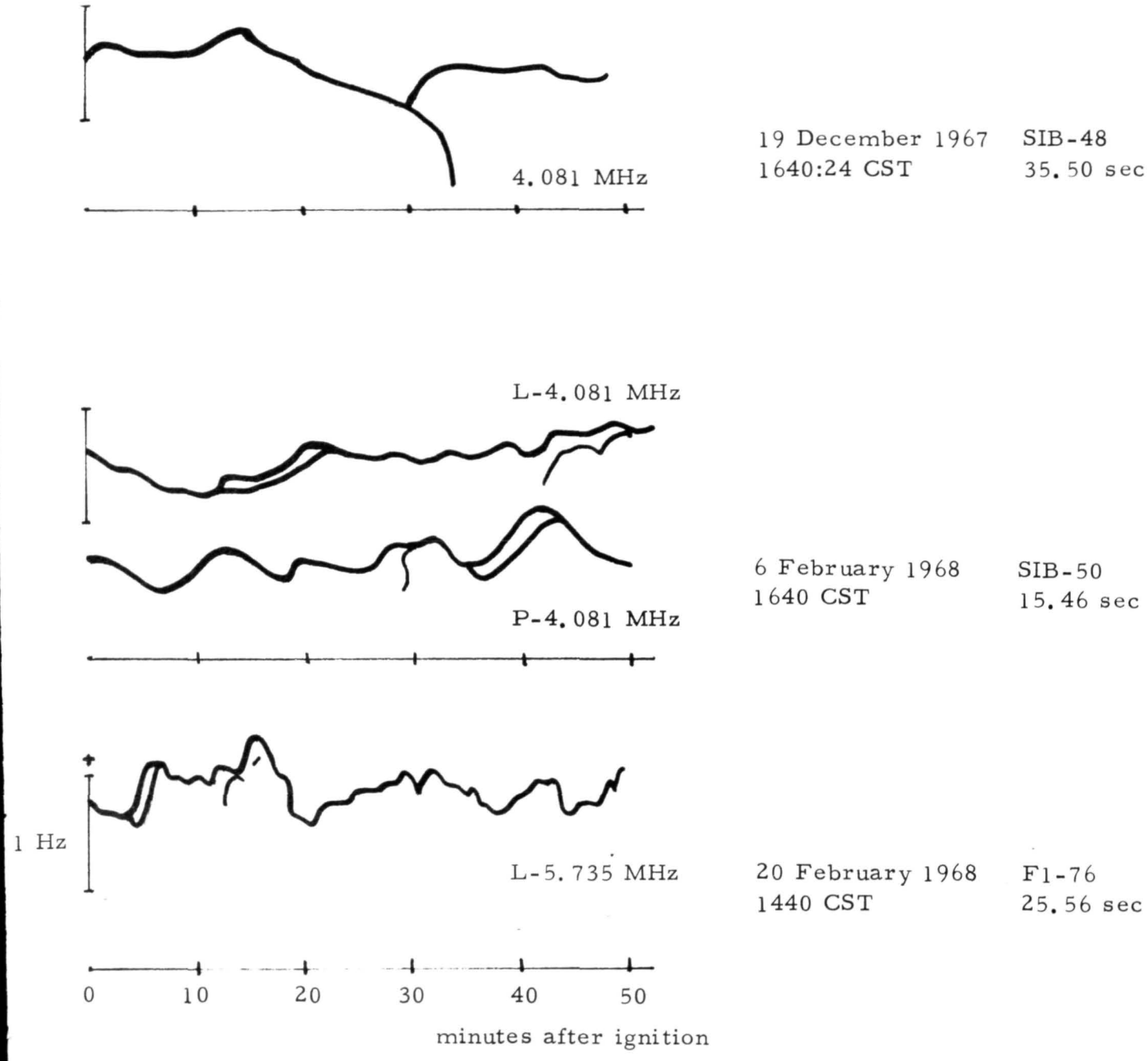


Figure 5: Tracings of Doppler data records, showing effects due to MSFC static rocket tests

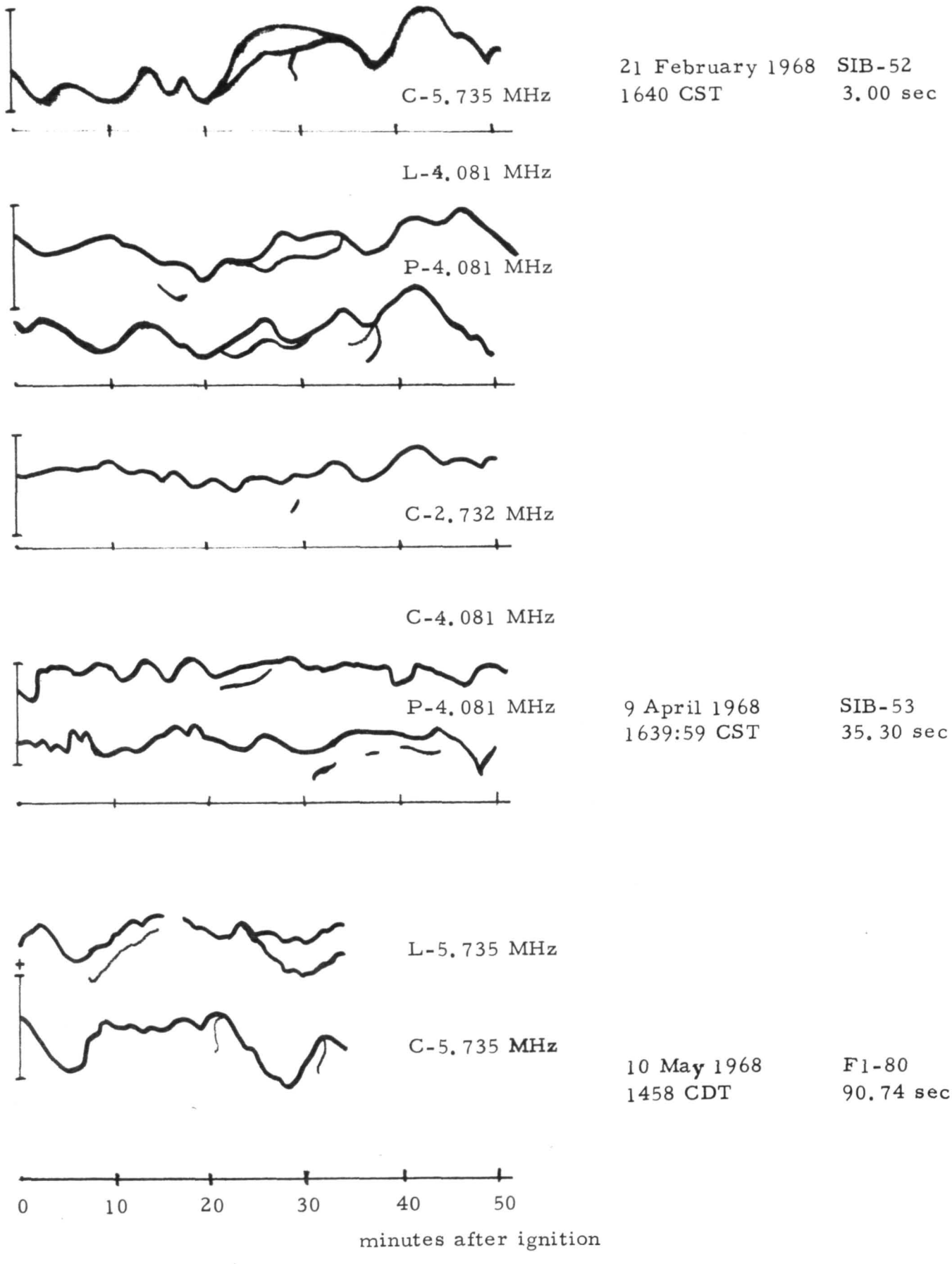


Figure 6: Tracings of Doppler data records, showing effects due to MSFC static rocket tests

main trace, but which occur for only a brief period and/or have an essentially constant negative amount of Doppler deviation with respect to the main trace.

The 20 April 1967 data is an example of the first type; the effects in the 3 August 1967 data which begin approximately 20 minutes after the onset of the test are an example of the second group; and the Limrock data for the 21 February 1968 test exhibits behavior of the third category.

The first two types of effects are suggestive of the presence of an overdense rising reflecting surface. In the first case a second reflecting raypath is established (not necessarily at vertical incidence) from the rising surface before it reaches the height of reflection of the main (and undeviated) signal. Due to refractive effects, as the height of reflection of this secondary surface nears that of the undisturbed raypath, the effective Doppler shift is decreased, until the two signal traces merge when the rising surface passes through the undisturbed reflecting region. In the second case, the secondary reflection is not established until after the rising front passes through the undisturbed reflection region, and it then continues to maintain a second raypath (probably at oblique angles) as the refractive effects of the reflecting region are diminished and the Doppler deviation reaches larger values more representative of the velocity of the frontal surface. This latter situation is similar to the effect observed when the principal vertical incidence reflection signal is lost at night due to the decrease of foF2 below the operating frequency, a good example of which is seen in the 6.185 MHz data shown in Figure 2 around 2000 CST.

The third class of traces, unlike those of the first two groups, show signal strength amplitudes similar to those of the main undisturbed traces, and exhibit a negative Doppler shift which does not meet at any point with the main trace. These suggest the formation of dense Sporadic-E-like clouds which move away from the test stands and the Doppler sounding path. It should be noted in this regard that the Sporadic-E-like echoes which were observed by SRI following the static tests which they monitored increased in apparent range with time, indicating either vertical propagation or (more likely, given that the sounder, located 48.5 km from the test stand, was probably receiving the echoes at oblique incidence) horizontal motions away from the observing region.

One fact to be noted about the data in Figures 3-6 is that none of these secondary traces is, unfortunately, unique to the static test period data (although their occurrence in general is rare), and one may draw one of two conclusions from this fact: either (a) these traces are not related to the static test occurrences, or (b) there are other sources of vertically propagating waves in addition to static tests. In any case, these traces are definitely not similar to those associated typically with horizontally traveling atmospheric waves, sometimes called traveling ionospheric disturbances (TID's).

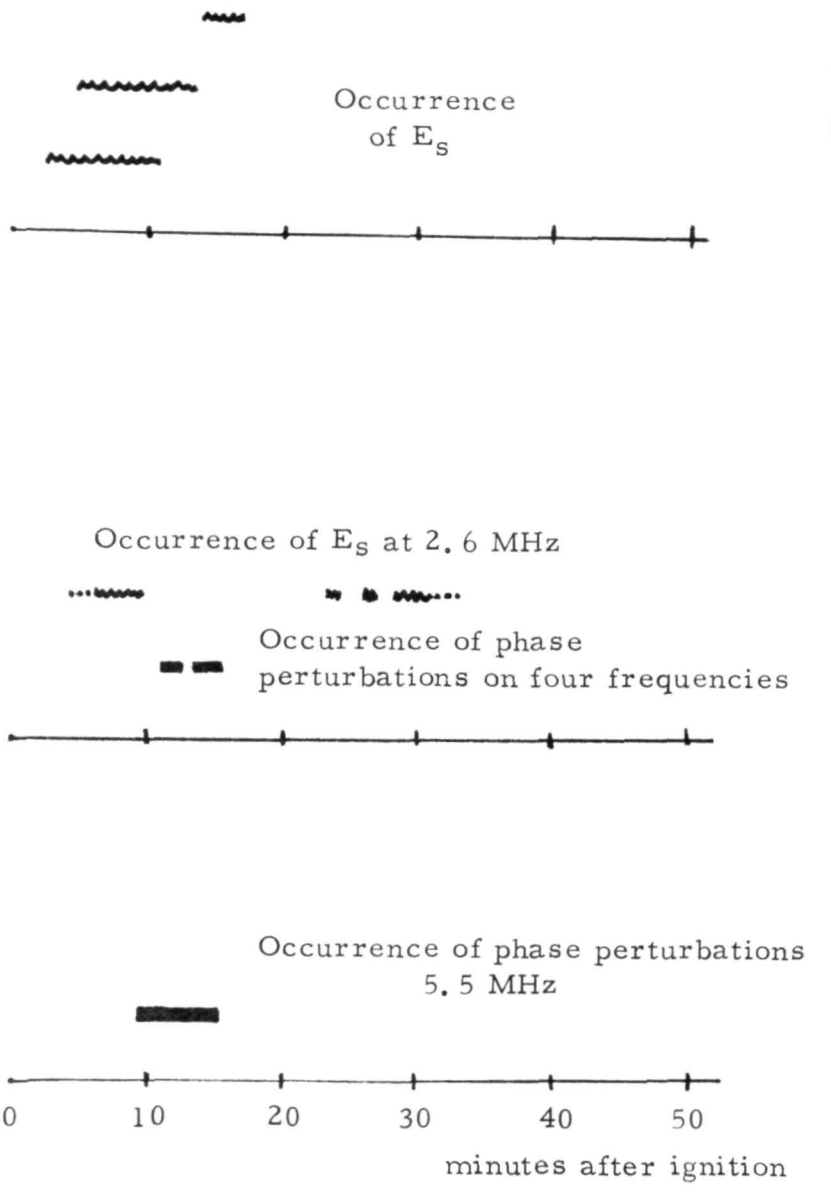
One other parameter to note is the length of time elapsing between the static firing and the onset of the ionospheric effects. The travel time for a vertically

propagating sound wave to reach an ionospheric height of 200 km from the ground should be on the order of 10 minutes, assuming an average sound speed of 300 m/sec. But no consistency is found in the candidate effects in this regard. Several of the apparent perturbations begin within a few minutes after the start of the test firing. Some occur within 10 to 20 minutes after the firing, which would be reasonable for simple acoustic propagation, and a number appear to onset after a 30 minute delay. Here again it is useful to consider the results of other experiments, and the data presented schematically in Figure 7 is intended to show the various delay times of the ionospheric effects which followed the aforementioned static rocket firings monitored by SRI and ITT, as well as the data obtained by Barry, Griffiths, and Taenzer of Stanford Research Laboratories (SEL) following the ground level explosion of TNT. It can be seen that time delays of the three basic orders observed in the Huntsville data also occurred in these cases. (The dotted lines extending from the E_s occurrences in the ITT data are intended to indicate that data records before and after the intervals covered by the solid lines were not available for analysis.)

More recently, Kaschak has reported on the times of arrival of low frequency acoustic waves at long distances from the trajectories of large launched rocket engines [13], showing the propagation of acoustic waves with supersonic velocities (500-1000 m/sec) and subsonic velocities (190-240 m/sec), in addition to the more usual waves with group speeds of the order of 300 m/sec. Further, any combination of one, two, or all of the three types of propagated waves may be observed following a particular launch. (Unfortunately, it has not been possible to date to detect acoustic waves associated with static rocket firings at long distances [14].) Thus, although the physical understanding of either the supersonic or subsonic wave propagation is at present lacking, it is clear that the firing of large rocket engines can produce waves of all three speed classes, and that the existence of these types of propagation can be used to explain the differing time delays found in the Huntsville observations.

It should be noted here that the Huntsville static firings did not produce any notable effects in microbarograph records taken during the sixe tests for which such data was available. This seems reasonable in view of what is known of the acoustic spectra of static tests, given the 30 second period upper frequency cut-off of the microbarograph sensors.)

From the preceding discussion, then, it is possible to suggest a model for the occurrence of atmospheric effects following ground level static tests of large rocket engines. Since the acoustic spectra of the <u>burn period</u> of static tests does not show adequate energy at frequencies sufficiently low enough to support propagation to high altitudes [5], it can be concluded that any upper atmospheric effect must be due to the shock waves generated at engine ignition and/or cutoff. These waves presumably degenerate into linear acoustic waves



SRI Tests: C-4 ionosonde
(48.5 km distant)

17 December 1964	1345 PST
12 February 1965	1055 PST
21 April 1965	1159 PST

ITT Tests: Vertical-incidence phase sounder with four fixed frequencies (~60 km distant)

24 February 1966 1901 EST

SEL Test: Two vertical-incidence phase sounders with two fixed frequencies each.

(85 km distant, in opposite directions)

17 July 1964 1058 MST

Figure 7: Schematic representation of onset times for other measurements of static test and explosion effects

(with a range of velocities) at some distance from the test location, and continue to propagate essentially vertically up through the ionosphere [11]. On some occasions the vertical temperature profile and the sequence of horizontal wind shears existing between the ground and the lower ionosphere are of such a nature that acoustic energy is not permitted to reach E or F region heights in detectable amounts. (See a discussion of this point in Appendix D.) On other occasions, conditions are favorable for the formation of Sporadic-E-like clouds, which move away from a position directly over the test stand with the wind speed prevalent at their height of formation. On yet other occasions a detectable wave continues to propagate to F region heights and produces a vertically propagating reflecting surface as it passes through the reflection region of the main signal. The velocities of propagation of the detected perturbations present a physical puzzle, but the SRI, ITT and Kaschak results present convincing evidence of both subsonic and supersonic acoustic wave propagation in addition to the expected sound speed motions.

One more interesting point should be considered here. In all the Doppler records showing perturbations following NASA/MSFC static tests, the candidate traces are of a secondary nature, existing in addition to the main and undisturbed signal return. In the case of the Barry, Griffiths, and Taenzer phase data, and in the two available cases of phase path records taken during static rocket tests (the ITT record of the 24 February 1966 test and the Avco phase-locked loop data of 3 August 1967 given in Figures 46-47 of Appendix C), the apparent phase perturbations appear in the principal reflected signal, and no secondary echoes or signals of any type are observed. Also, in these latter two cases the maximum Doppler shift calculable from the phase data is less than 0.1 Hz, and in the case of the ground level TNT explosion the maximum Doppler shift would approach 1.5 Hz (since the explosion contained rather large energies at much lower frequencies than is the case of static tests[5]).

It seems therefore that if a simple acoustic wave were propagating upward with normal sound speed from any of the Huntsville static tests, it might not be observed in the Doppler records due to the small frequency shift which it would likely produce. Thus perhaps the only effects which might be observed in addition to Sporadic-E would be the motions of secondary reflecting fronts whenever they might exist and if they possessed sufficient density perturbations. This is because the Doppler measurement technique is particularly sensitive to signals being returned with substantial frequency shift, even though the signal strength amplitudes of the returns may be small. It seems clear that, with the difficulties apparent in relating small Doppler perturbations to specific static tests, a vertical incidence phase sounding measurement approach would be strongly recommended for any further investigations of this nature.

The evidence amassed in this section for the existence of ionospheric perturbations generated by the static firing on the ground of large rocket engines

leads convincingly to the conclusion that such coupling can occur. Taken individually, the Doppler data records collected in the Huntsville experimental program are not adequate to demonstrate this coupling, but taken together as a group they do permit the conclusion that low frequency acoustic waves can propagate from the static test event to ionospheric heights and create observable Doppler perturbations there. It may also be stated that strong evidence exists for modes of acoustic wave propagation at both supersonic and subsonic speeds.

IV. THUNDERSTORM OBSERVATIONS

As a result of an initial suggestion made by Pierce and Coroniti[15], one of the purposes of this experiment has been to look for ionospheric Doppler variations which might be related to meteorological phenomena. Various indirect evidence, largely statistical, for relating meteorological and ionospheric effects has been presented over the years (a summary is given in Reference 5), but until recently no evidence linking specific disturbed weather conditions with specific ionospheric events had ever been presented.

The concept of Pierce and Coroniti grew out of the fact that certain frequencies of atmospheric pressure oscillations are preferred for vertically propagating pressure waves[3], and these are present in significant magnitudes in the thunderstorm cloud-top oscillation data reported by Anderson[16]. There is now some doubt as to whether the vertical motions of individual cumulus towers possess sufficient energy (although Pierce and Coroniti estimate 10^{17} ergs for a single oscillating cumulus tower) to produce detectable effects at ionospheric heights. Nor do the thunderclaps occurring in meteorological storms possess sufficient energy at low enough frequencies to generate ionospheric disturbances[17]. But as a result of Pierce and Coroniti's suggestion, Georges of ITSA/ESSA began looking in his steep incidence Doppler sounding records (taken on a network of paths surrounding Little Rock, Arkansas) for variations related to meteorological phenomena, and reported twelve instances in which he observed extended sequences of otherwise rare oscillations with three to four minute periods[3, 18]. And in each case he found strong echoes in weather radar data taken in the vicinity of his observing stations. According to Georges, these oscillations can persist intermittently for several days, have no apparent connection with geomagnetic or solar activity, exhibit an apparent upward phase velocity when seen on multi-frequency soundings, and are sufficiently localized geographically as to appear only on those paths of his network which are themselves located over the radar-indicated disturbance region. In every case of the appearance of these oscillations on the Doppler records which he examined, a weather disturbance was also present; the converse was not true, however.

The Huntsville Doppler records have since been examined for evidences of similar three-to-four minute period oscillations, with a number of occurrences being found. Figure 8 shows a 2.735 MHz vertical incidence cw phase record taken with the Avco phase-locked loop device which was tested for a short period at Huntsville[5]. Thunderclouds were visible shortly after 1400 CDT, as indicated by site personnel on the record, and the hourly weather radar summary plots for this day show signs of disturbed weather conditions developing over Huntsville between 1345 and 1445 CDT. The phase oscillations exhibit periods between two to three minutes,

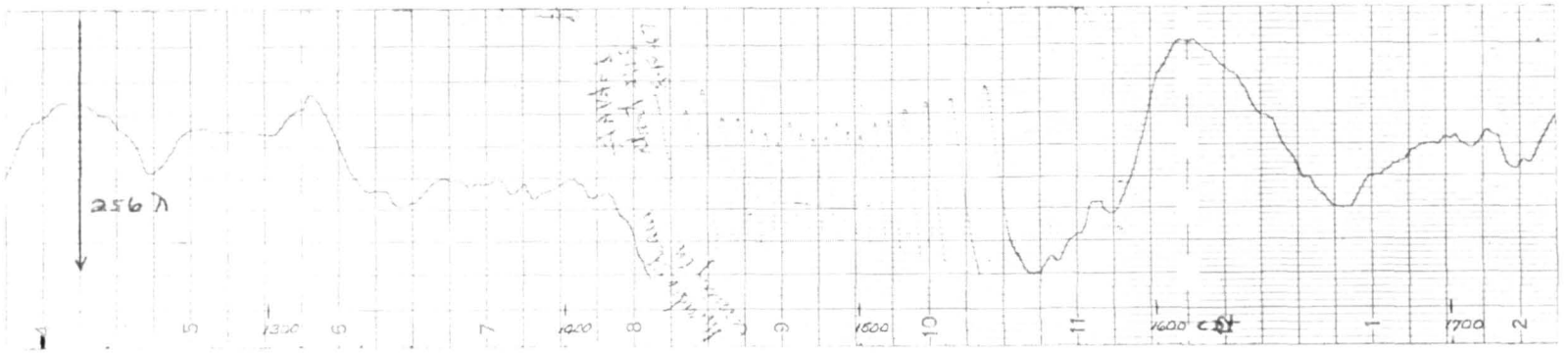


Figure 8: Phase-locked loop data showing thunderstorm effects, 18 August 1967: Huntsville, Alabama

and cease at about 1530; the weather radar records show a removal of the disturbance from the Huntsville area between 1545 and 1645 CDT. The vertical incidence Doppler records taken during this period did not give any positive indication of similar oscillatory behavior, however.

Figures 9(a)-9(d) contain twenty hours of Doppler records which exhibit the most marked occurrence of 3-5 minute period oscillations observed in the data collected at Huntsville, The oscillatory behavior begins at about 2200 CDT on 15 May 1968 and lasts to 0630 CDT on 16 May. The weather radar summary charts first show disturbed regions over the Huntsville area on the 2245 CDT hourly map for 15 May, and these continue until the 1145 CDT map the following day. There is an abrupt cessation of the Doppler oscillations at sunrise, even though the storm activity continues into the morning.

The most remarkable feature of this record is the fact that for each frequency on which these oscillations are visible, they are in phase (within the 30 seconds resolution of these particular records) on the two or three transmissions present. This means that the ionospheric reflection regions under surveillance at each frequency are moving up and down together under the influence of a vertically propagating wave. That this effect could not be produced by any horizontal wave motion can be seen by considering the horizontal separation distances of the three ionospheric reflection points shown in Figure 1 (b). Even at the sound speed of 300 m/sec, it would take on the order of 2 1/2 minutes for a horizontally propagating wave to travel between the Pulaski and Limrock path reflection points. Or in the worst case, if a wave were moving horizontally in a direction perpendicular to the line between the Limrock and Pulaski sites, at 300 m/sec it would take 74 seconds for it to pass from the reflection points of those two paths to that of the Cotaco path (along the line marked "minimum time delay path"). Thus the oscillations must be due to vertically propagating wave motions with periods of 3-5 minutes. In contrast, the oscillations present in the Doppler records before 2000 CST, at which time the Fredricksburg magnetograms show mildly disturbed behavior, are out of phase by the order of minutes on any given frequency. The magnetic disturbance condition subsides after 2000 CST, and no indication of magnetic activity is present during the 3-5 minute period oscillations sequence.

Figure 10 contains 5 1/2 hours of Doppler records taken on 11 March 1968, showing the beginning of a sequence of 3-4 minute period oscillations beginning at about 1950 CST in the higher frequency records. A tornado was sighted near Huntsville at about 2000 CST, and the weather radar summary charts show the first signs of severe weather disturbances in the hourly map issued at 1945 CST; these continue to at least 2345 CST. (No Doppler data was recorded after 2302 CST.) No indication of disturbed magnetic conditions is present in the Fredricksburg magnetograms for this period, and again the oscillations are in phase for each frequency on which transmission were recorded.

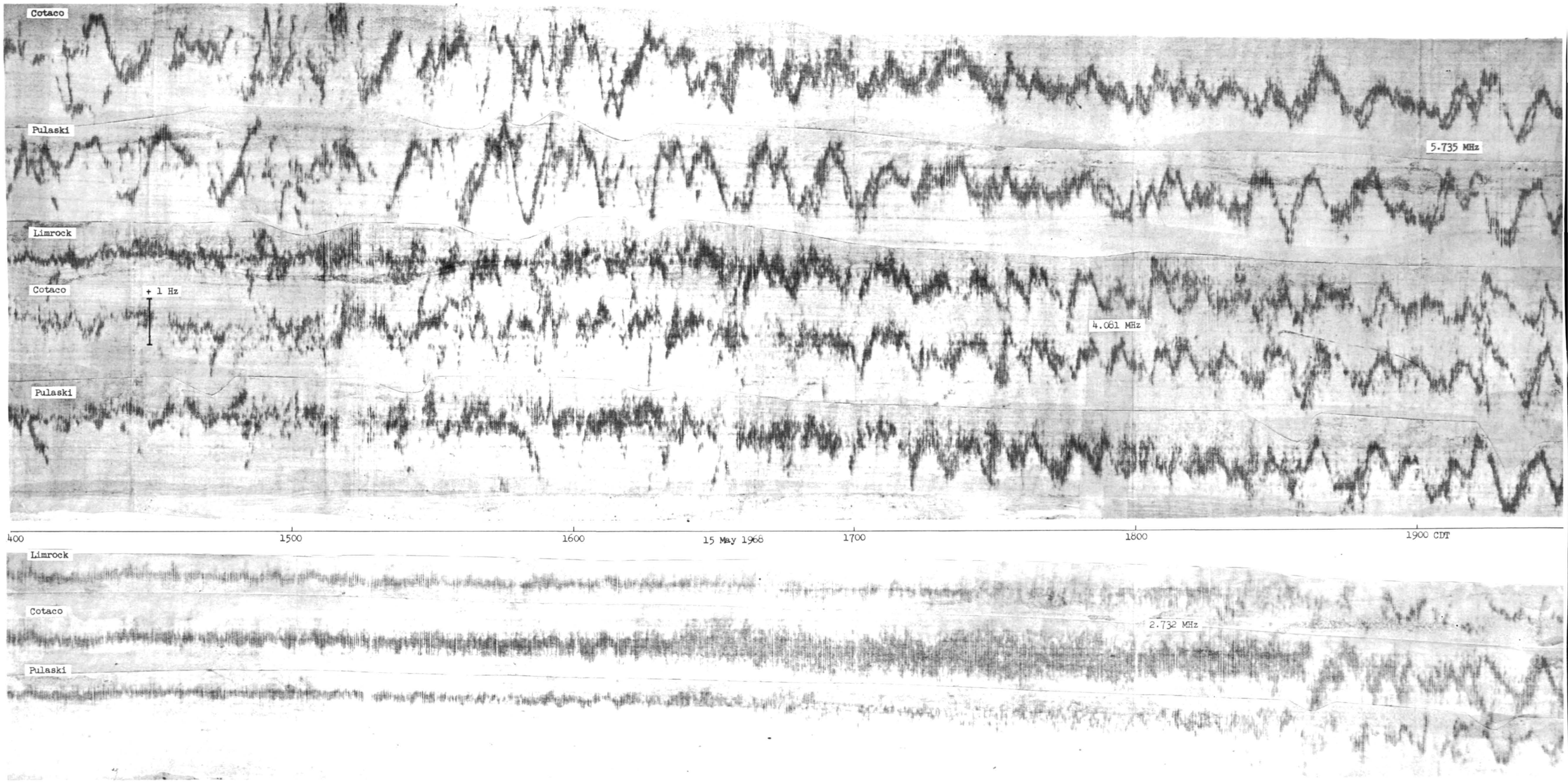


Figure 9 (a): Doppler data showing thunderstorm effects,
15-16 May 1968: Huntsville, Alabama

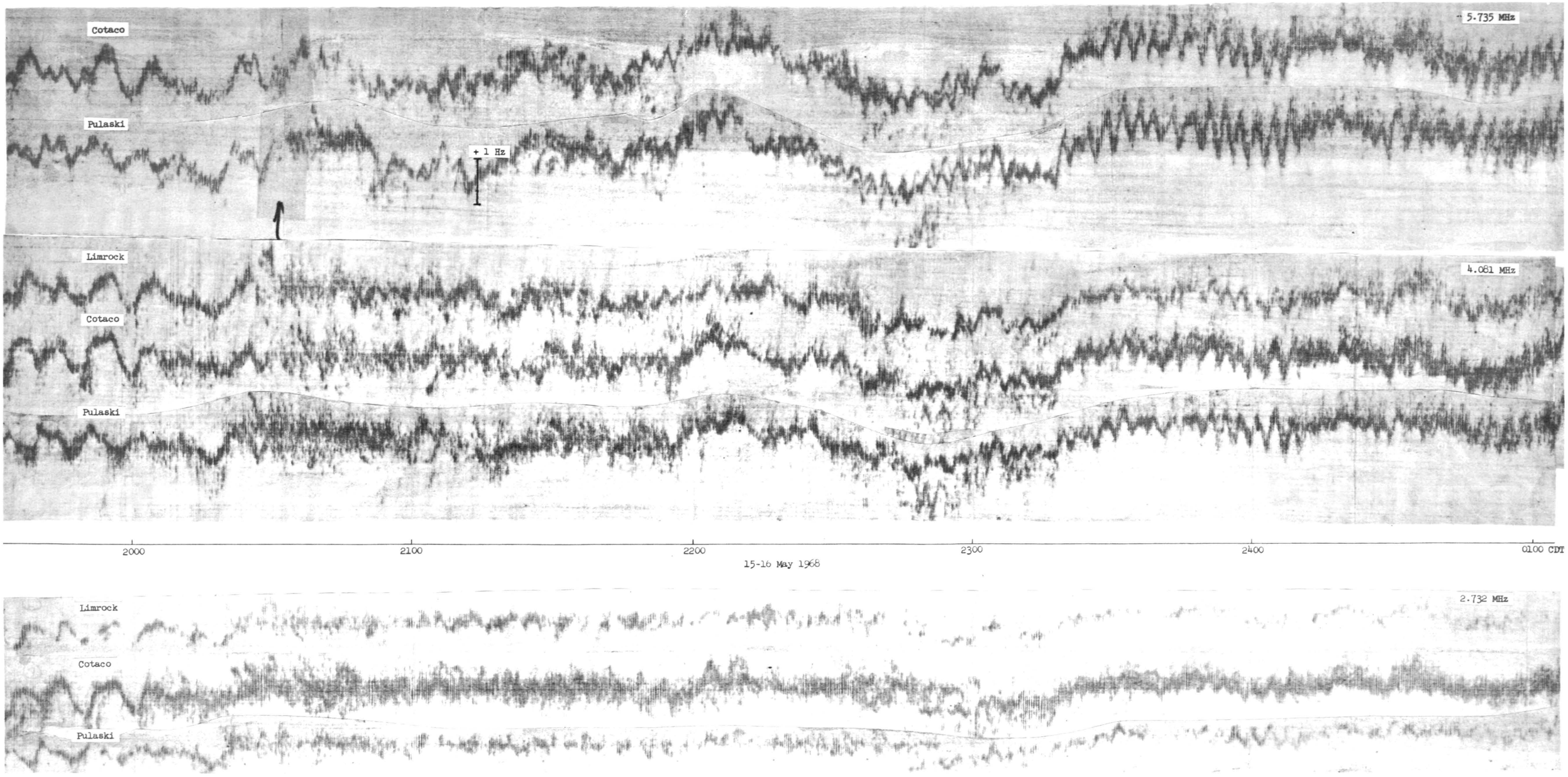


Figure 9 (b): Doppler data showing thunderstorm effects,
15-16 May 1968: Huntsville, Alabama

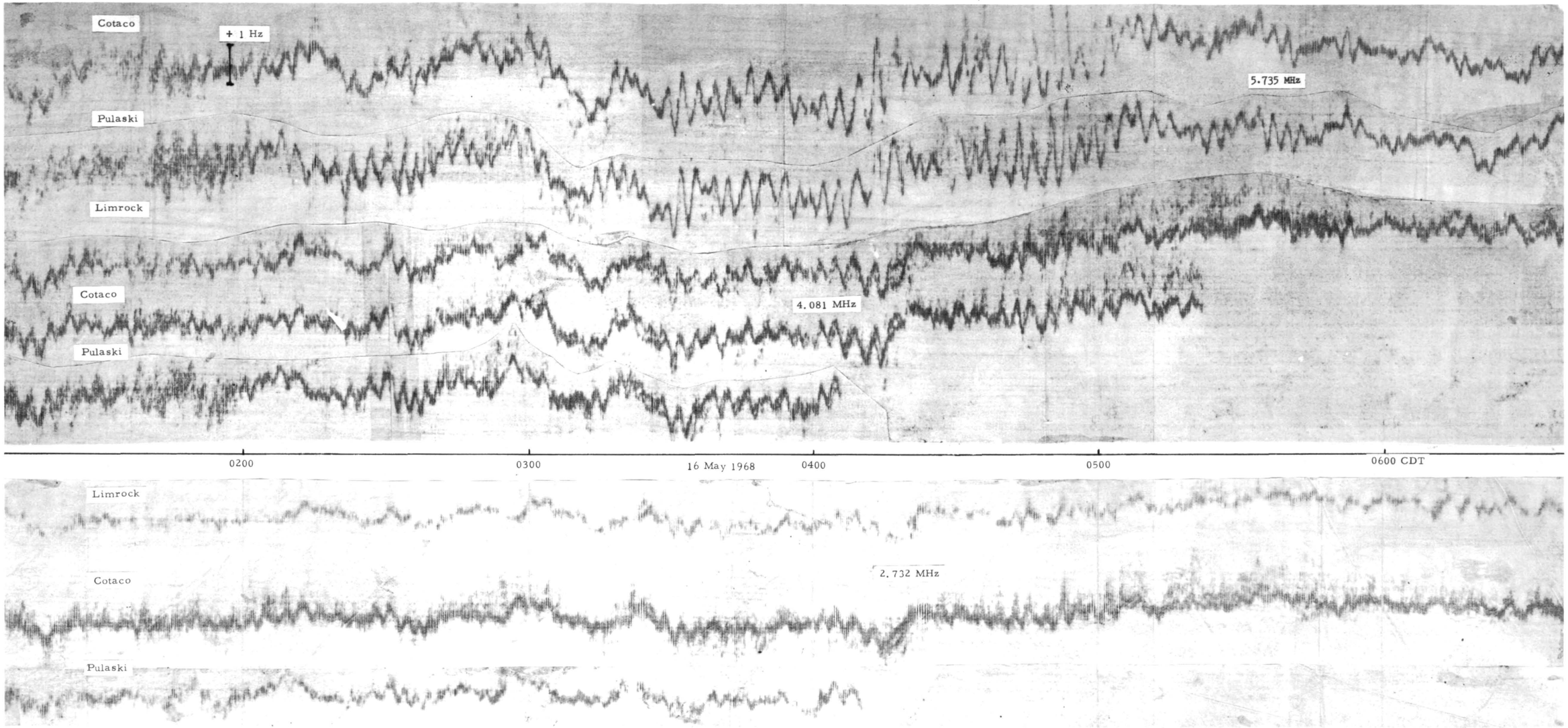
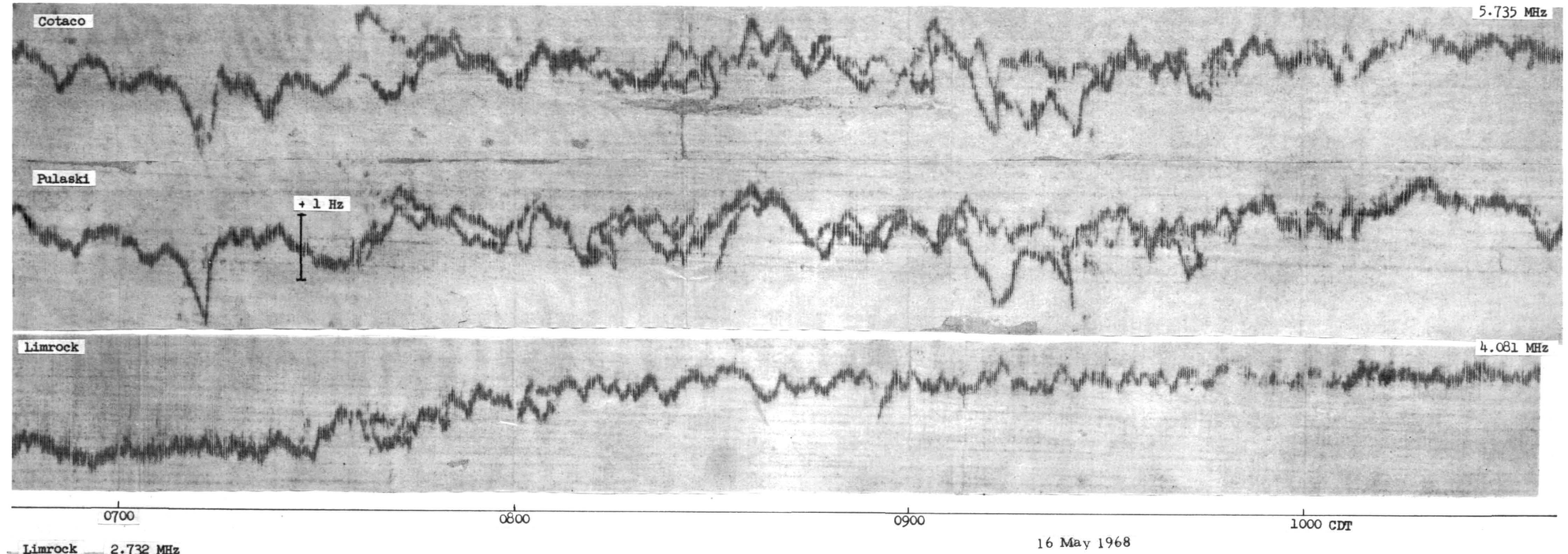


Figure 9 (c): Doppler data showing thunderstorm effects,
15-16 May 1968: Huntsville, Alabama



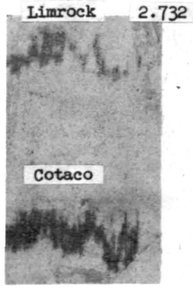


Figure 9 (d): Doppler data showing thunderstorm effects,
15-16 May 1968: Huntsville, Alabama

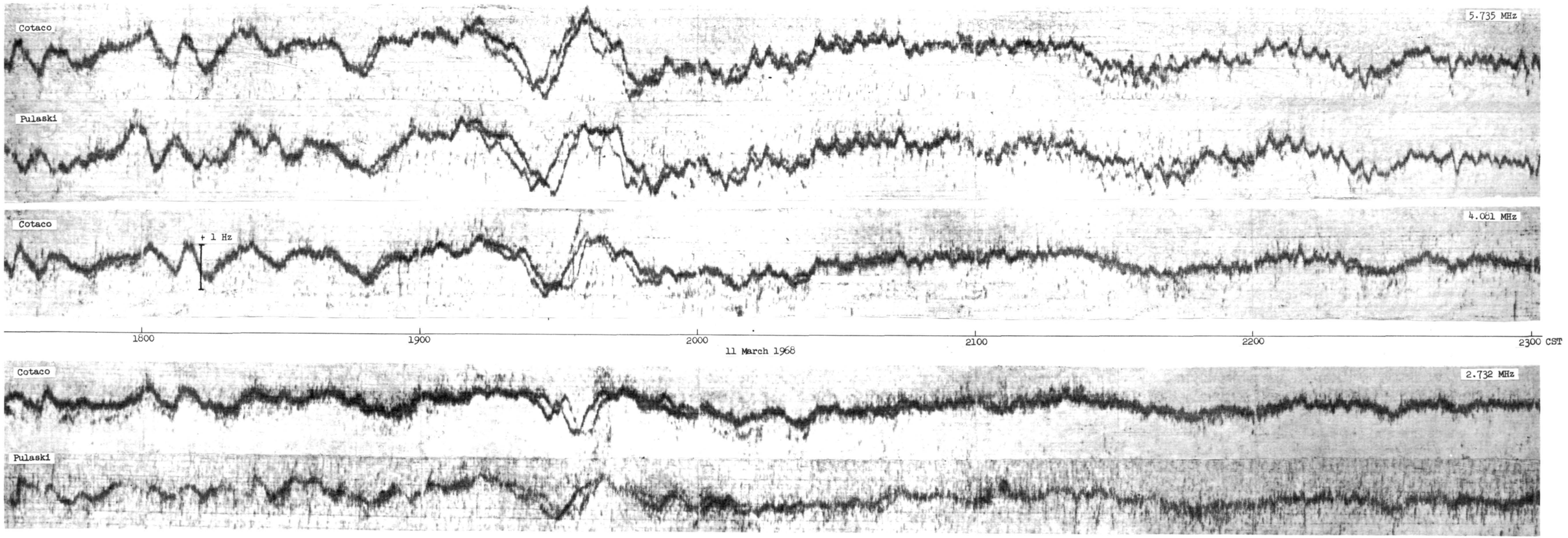


Figure 10: Doppler data showing thunderstorm effects,
11 March 1968: Huntsville, Alabama

It is important to note that without the presence of three simultaneous and spatially separated transmissions on a single frequency, it would not be possible to positively identify the existence of vertically propagating waves. For example, with two paths it could always be conjectured that a horizontally propagating wavefront was in operation with a fortuitous directional orientation that caused it to onset at both reflection points at essentially the same instant of time. But his cannot be the case when the oscillations show phase concurrence over three different paths with reflection regions separated by distances between 26 and 48 km. Thus, these data provide the first positive identification of the vertically propagating nature of the waves associated with the characteristic 3-5 minute oscillatory periods.

Not all the Doppler data recorded during the entire Huntsville experimental program has been reprocessed with the expanded frequency scale spectral analysis which is necessary to detect these small oscillations, so no statistics of occurrence of this phenomenon are available at this reading. The next step in any further analysis of the meteorological coupling phenomenon using this data would be to survey all the Doppler records (after they have been appropriately processed) for occurrences of these oscillations. Then the hourly weather radar summary charts should be scanned during all the hours that the Huntsville Doppler sounding experiment was operated, and a list compiled of all the times during which severe weather disturbances were present in the Huntsville area. The size of the logical intersection of these two sets of data, compared particularly with those cases in which Doppler oscillations were observed when no weather disturbances were extant, would then provide a measure of the confidence that should be placed in the interpretation that these oscillations are indeed caused by thunderstorms below. Those periods in which thunderstorm activity occurred without producing detectable ionospheric oscillations -- and these should be numerous -- would likely indicate the presence of conditions in the temperature and wind profiles of the intervening atmosphere which inhibit the upward propagation of acoustic waves at these frequencies.

The evidence of Georges and the results detailed above, lend considerable weight to the identification of the 3-5 minute period oscillations in the Doppler records as indications of tropospheric-ionospheric coupling through the mechanism of long period acoustic waves. Further analysis along the lines discussed above, and additional measurements during months when storms are characteristically frequent, should aid in evaluating this tentative conclusion.

V. OTHER PHENOMENA

Three other types of Doppler perturbations are worth noting, because their unique appearance clearly signals their presence when they occur. On some mornings following ionospheric sunrise, a sequence of long period oscillations is present for an hour or so, as illustrated in Figure 11. Here the variations have a period of approximately 20 minutes, and persist for perhaps 70 minutes. On the day previous to this record, no oscillatory behavior of note is observed during or following sunrise. Both of these days are among the five magnetically most quiet days in April, and no indications are present on the Fredricksburg magnetograms to distinguish the two sunrise periods. The relationship of these apparent motions to the occurrence of sunrise seems fairly clear, but no explanation is presently available for their generation or, for that matter, their lack of generation, on any particular day.

Figure 12 shows some 12 hours of Doppler records, the feature of interest being the spreading in the Doppler signals occurring on all frequencies between 0000 and 0300 CST. The magnitude of the spread increases with signal frequency, and all the traces show the presence of several very long period oscillations, the amplitude of which also increases with frequency. One possible explanation of this effect, which has been observed on a number of different occasions, is the occurrence of Spread-F conditions in the ionosphere over Huntsville. Without ionogram data it is not possible to confirm or disprove this, and the correct explanation is still an open question. March 24 was one of the five magnetically disturbed days of March 1968, and this correlation appears to prevail in the several other cases of this phenomenon which have been observed in the Huntsville Doppler records.

Figure 13 shows the simultaneous occurrence of a series of several oscillations on all frequencies and paths, with a period of approximately three minutes, beginning at 0010 CST on 21 April 1968. The Fredricksburg magnetograms show similar oscillations in all components at this same time. Norman Chang of ITSA/Boulder indicates that this effect is occassionally observed in all Doppler records, always accompanied by magnetogram oscillations, but that its nature is not presently understood. [19] He reports that similar oscillations appear in the ITSA/Boulder Doppler records at the same time on 21 April.

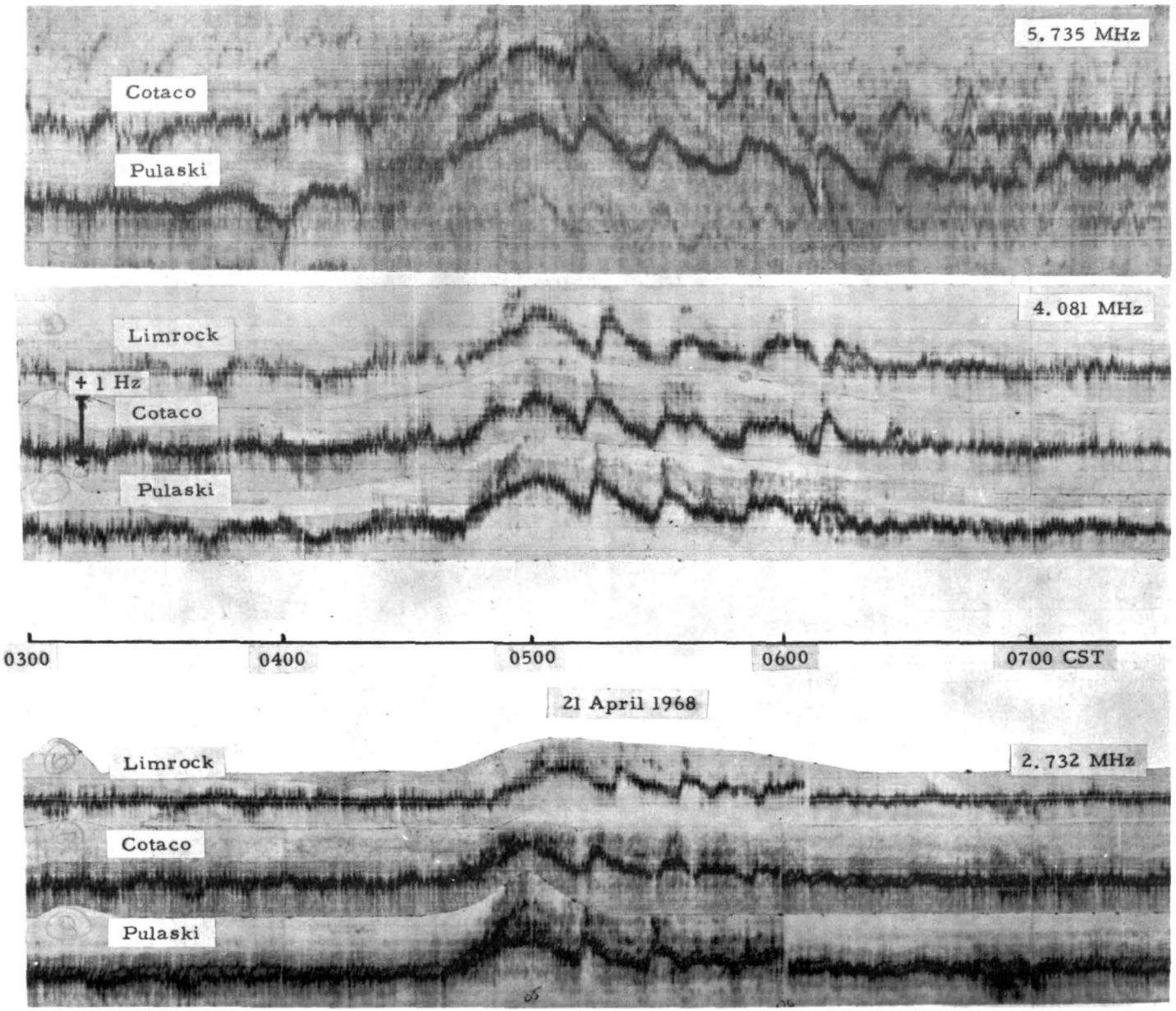


Figure 11: Doppler data showing sunrise effects, 21 April 1968: Huntsville, Alabama

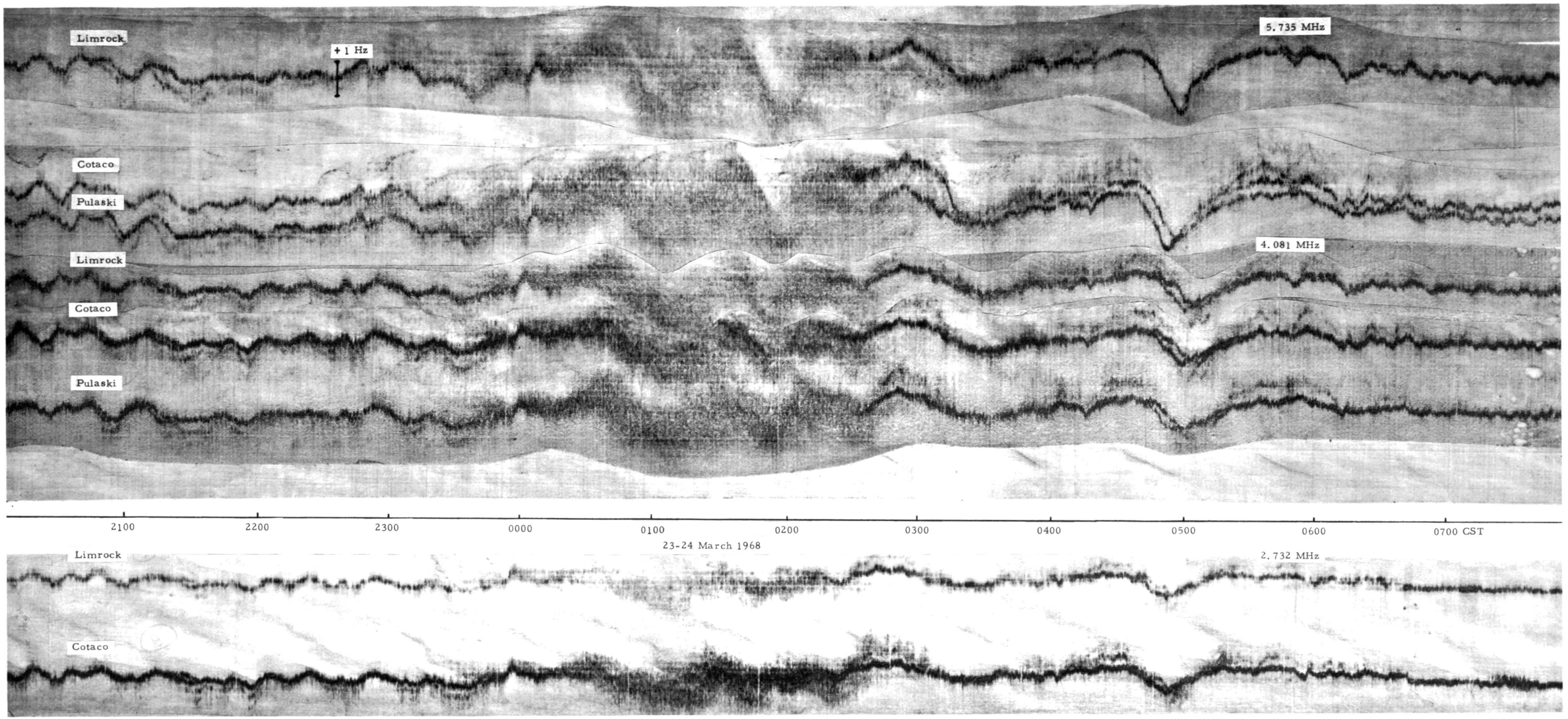


Figure 12: Doppler data showing frequency spreading
23-24 March: Huntsville, Alabama

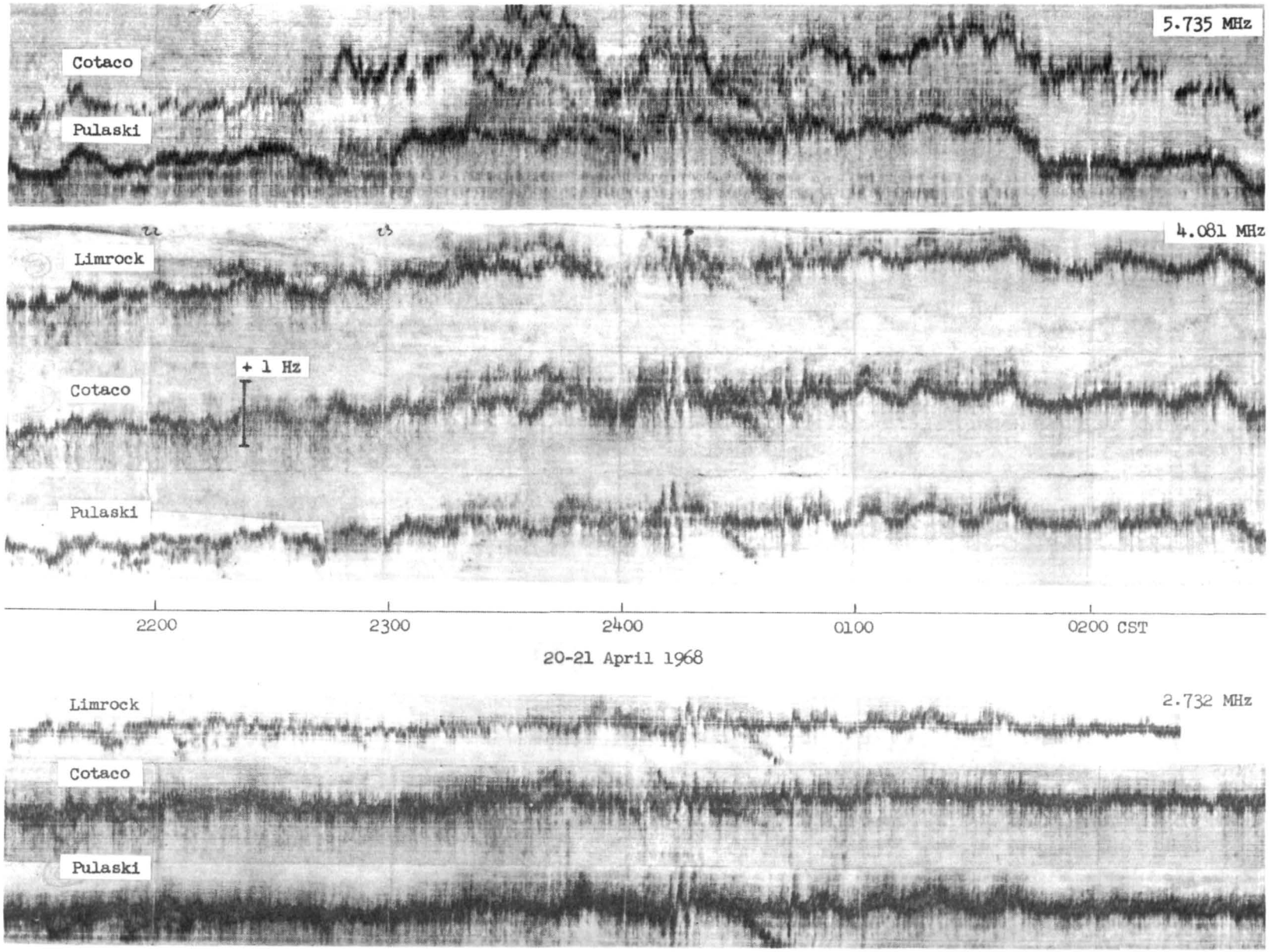


Figure 13: Doppler data showing unusual oscillatory behavior
20-21 April 1968: Huntsville, Alabama

VI. CONCLUSIONS

It is clear that the results of this study, taken with similar measurements reported elsewhere, demonstrate that it is possible for ground level sources to generate acoustic waves of adequate energy and sufficiently low frequency to propagate upward to ionospheric heights. Some of the resultant electron density perturbations in the ionosphere are subsequently detectable by hf vertical incidence Doppler sounding techniques.

In the case of static firing tests of large rocket engines, it has been shown that, in addition to the expected vertically propagating simple acoustic waves traveling with the speed of sound in the medium, it is possible on occasion for the test to generate waves with both higher and lower velocities. In many instances, however, no Doppler observable ionospheric perturbations are produced whatsoever.

In the case of local thunderstorms, evidence has been added to a growing body of data which demonstrates that long sequences of ionospheric oscillations with periods in the 3-5 minute range may be produced by low frequency acoustic waves propagating upward from meteorologically disturbed regions. In particular, data has been shown which proves that these waves are indeed propagating vertically, as distinguished from the common horizontal wave motions which are constantly present in the ionosphere.

It can be inferred from the discussions of the difficulties of detecting small amplitude, slowly varying motions in the ionosphere with the Doppler sensing technique(primarily because it is a velocity sensitive measurement)that, in the cases of both static rocket tests and local thunderstorms, it would be of considerable assistance to employ a radio sensing technique with more sensitivity to the small scale perturbations in electron density occurring in the radio raypath reflection region. The hf vertical incidence phase sounding technique has been shown, in other experiments discussed in this report, to possess a substantial capability in this regard, and it is therefore recommended that implementation of such instrumentation be seriously considered in any further experimental programs of this type.

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33. Smith, R. E. and D. K. Weidner, Space Environment Criteria Guidelines for Use in Space Vehicle Development (1968 Revision), NASA TMX-53798, October 1968.

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APPENDIX A

MODIFICATIONS TO HEATHKIT DX60-A TRANSMITTERS

(Prepared by Michael Thomas, Avco/Huntsville)

The Heathkit DX-60A amateur transmitters selected for use in this experiment proved to be unreliable when operated continuously for long periods of time in the cw mode. Several minor circuit changes were required to alleviate this condition. It was also necessary to adjust inductors L2 and L3 to allow the transmitters to operate at frequencies other than those in the normal amateur bands (refer to the transmitter schematic drawing in the manufacturer's manual for the circuit elements described here).

Modifications

1. Resistors R10 and R30 were changed from 4700 ohms and 22K ohms, respectively, to 12 K ohms and 15K ohms. The purpose of this change is to shift the bias point of the power amplifier tube from about -40 volts to about -60 volts and thus to prevent the tube from destroying itself should the drive signal be lost.

2. Resistor R28 was changed from 10K ohms at 2W to 10K ohms at 5W, since under normal operating conditions this resistor dissipates about 1.5W.

3. Cathode bias was added to both of the 6CL6 tubes. This was done with a 330 ohm 1/2W cathode resistor and a 0.1 mf 50V bypass capacitor. Without this modification the plate current becomes excessive if the drive signal is removed.

4. Tank coil L2 was removed and replaced with several molded rf chokes (National type R-1550). These chokes are soldered directly to the switch wafer, relieving the necessity of tapping a continuously wound coil. The exact value of the coils depends upon the desired frequencies.

5. The power amplifier tank coil L3 was replaced by a section of Air Dux #1410T coil stock and then tapped at the appropriate points.

APPENDIX B

DATA COLLECTION LOG

Tape No.	Date	Start Time	Stop Time	Frequencies
96	9/27/67	1526 CDT	0405 (9/28)	Cotaco 2.732 MHz 4.081 6.185
97	9/28	0741	1525	Pulaski 4.081 6.185
98	9/28	1529	0406 (9/29)	
99	9/29	0747	1538	
100	9/29	1545	0400 (9/30)	
101	10/2	0745	1610	
102	10/2	1615	0430 (10/3)	
103	10/3	0750	1600	
104	10/3	1610	0425 (10/4)	
105	10/4	0845	2100	
106	10/5	0800	1530	
107	10/5	1535	0350 (10/6)	
108	10/9	0810	1530	
109	10/9	1535	0350 (10/10)	
110	10/10	0800	1520	
111	10/10	1530	0345 (10/11)	
112	10/11	0745	1520	
113	10/11	1530	0345 (10/12)	
114	10/12	0745	1525	
115	10/12	1535	0350 (10/13)	
116	10/13	0815	2030	
117	10/16	0813	1545	
118	10/16	1547	0402 (10/17)	
119	10/17	0751	1526	
120	10/17	1531	0346 (10/18)	
121	10/18	0753	1531	
122	10/18	1535	0350 (10/19)	
123	10/19	0750	1535	
124	10/19	1537	0352 (10/20)	
125	10/20	0753	1535	
126	10/20	1545	0400 (10/21)	
127	10/23	0800	1615	
128	10/24	0755	1610	
129	10/25	0745	1542	
130	10/25	1545	0400 (10/26)	
131	10/26	0807	1622	
132	10/27	0857	1530	
133	10/27	1532	0347 (10/28)	
134	10/30	0745 CST	1530	

Tape No.	Date	Start Time	Stop Time	Frequencies
135	10/30/67	1535 CST	0350 (10/31)	
136	10/31	0745	1552	
137	10/31	1555	0410 (11/1)	
138	11/1	0809	2024 (11/2)	
139	11/2	0800	2015 (11/3)	
140	11/7	0854	2109 (11/8)	
141	11/16	1115	2330	
142	11/30	0759	1534	Cotaco 2.732 MHz 4.081 5.735
143	11/30	1536	0351 (12/1)	Pulaski 2.732 4.081 5.735
144	12/1	0750	1545	Limrock 2.732 4.081 5.735
145	12/1	1543	0358 (12/2)	
146	12/2	1145	2400	
147	12/7	0920	2135	intermittent operation of Pulaski and Limrock transmitters
148	12/9	1510	0325 (12/10)	
149	12/11	0843	2058	
150	12/18	0810	2025	
151	12/19	0737	1952	
152	12/20	0810	2025	
153	12/21	0756	2011	
154	12/27	1538	0353 (12/28)	
155	1/3/68	1540	0355 (1/4)	
156	1/25	1145	2355	Cotaco, Pulaski, Limrock 2.723 MHz 4.081 5.735
157	2/6	1430	1555 (2/8	
158	2/12	0900	1000 (2/14)	
159	2/14	1330	1520 (2/16)	
160	2/16	1530	1630 (2/18)	
161	2/19	0800	1010 (2/21)	
162	2/21	1025	1225 (2/23)	
163	2/23	1245	1300 (2/25)	
164	2/28	0855	1000 (3/1)	
165	3/4	1530	1630 (3/6)	
166	3/7	0755	0855 (3/9)	
167	3/11	0750	0800 (3/13)	
168	3/13	0805	1400 (3/15)	

Tape No.	Date	Start Time	Stop Time	Frequencies
169	3/15/68	1500 CST	1600 (3/17)	
170	3/18	0750	0805 (3/20)	
171	3/20	0810	0745 (3/22)	
172	3/22	0750	0850 (3/24)	
173	3/27	0800	0800 (3/29)	
174	3/29	0810	0910 (3/31)	
175	4/1	0740	0740 (4/3)	
176	4/3	0750	0740 (4/5)	
177	4/5	0745	0845 (4/7)	
178	4/8	0755	0855 (4/10)	
179	4/11	0750	0850 (4/13)	
180	4/15	0800	1520 (4/17)	
181	4/17	1530	1535 (4/19)	
182	4/19	1540	1640 (4/21)	
183	4/22	0825	1530 (4/24)	
184	4/24	1535	1540 (4/26)	
185	4/26	1540	1640 (4/28)	
186	4/29	0755 CDT	0810 (5/1)	
187	5/1	0815	0915 (5/3)	
188	5/3	1500	1600 (5/5)	
189	5/6	1510	1610 (5/8)	
190	5/9	0740	1530 (5/10)	
191	5/10	1535	2205	
	5/15	0730	0115 (5/17)	
192	5/27	0814	0816 (5/29)	
193	5/29	0820	0820 (5/31)	

APPENDIX C

DOPPLER DATA RECORDED DURING STATIC TESTS AT NASA/MSFC

Table 2 lists all the NASA/MSFC static rocket engine tests which have been monitored by the Doppler sounding experiment at Huntsville, including data taken under both the preceding RADC program and the present study reported here.

As discussed in Section III of this report, all the static test Doppler records were reprocessed with uniform time and frequency scales on the narrowband Rayspan analyzer at an effective speedup factor of 128 times. This results in a frequency display with approximately 1.3 Hertz per record inch, with a processing resolution of 1/12 Hertz. Figures 14 through 41 in this Appendix reproduce those records.

Figures 40(b) - (d) are reproductions of the same data interval, processed with increasing gain in the spectrum analyzer, to illustrate the problems encountered in identifying small amplitude signal traces in the presence of other strong signals. It should be clear from these three records that intensity modulating the displayed signal trace to indicate amplitude levels is an inadequate, though efficient, processing technique when more than a few decibels of amplitude resolution are encountered.

Figures 42 through 48 are reproduced from a report written earlier during the course of this experimental program [5]. They contain Doppler data processed with different time and frequency scales and resolutions, and are given here to aid in the interpretation of certain small amplitude traces which are related to the static firing events (see Section III). Figures 46 and 47 show phase path variations and perturbations recorded with the Avco phase-locked loop monitoring device [5] operating during the 3 August 1967 test.

Table 2

NASA/MSFC Static Test Firings Monitored
by the Doppler Sounding Experiment

Tape No.	Date	Start Time	Duration	Booster
1	4/20/67	1301 CST	40 seconds	F1-61
13	5/9	1705:31 CDT	35.3	S1B-46
18	5/19	1328:06	25.004	F1-62
20	5/22	1733	145.7	S1B-47
20	5/22	1800:59	46.004	F1-63
32	6/9	1300	41	F1-64
38	6/14	1400	41	F1-65
53	8/1	1500:00	3	S1C
54	8/3	1920:00	40	S1C
71	8/16	1352	41	F1-68
88	9/1	1103	46	F1-69
97	9/28	1303	44.39	F1-70
123	10/19	1300	45.18	F1-71
131	10/26	1311:57	43.70	F1-72
141	11/16	1316 CST	45.31	F1-73
142	11/30	1313	44.85	F1-74
151	12/19	1640:24	35.50	S1B-48
156	1/25/68	1708	15.50	S1B-49
157	2/6	1640	15.46	S1B-50

Table 2 (Cont'd)

NASA/MSFC Static Test Firings Monitored
by the Doppler Sounding Experiment

Tape No.	Date	Start Time	Duration	Booster
159	2/14	1630:01 CST	15.20	S1B-51
161	2/20	1306	0.00*	F1-75
161	2/20	1440	25.56	F1-76
162	2/21	1640	3.00	S1B-52
167	3/12	1337	25.75	F1-77
170	3/19	1257	25.44	F1-78
173	3/27	1258	26.54	F1-79
178	4/9	1639:59	35.39	S1B-53
183	4/23	1640	145.30	S1B-54
190	5/10	1458 CDT	90.74	F1-80
191	5/15	1535	121.30	F1-81

* Test aborted during ignition

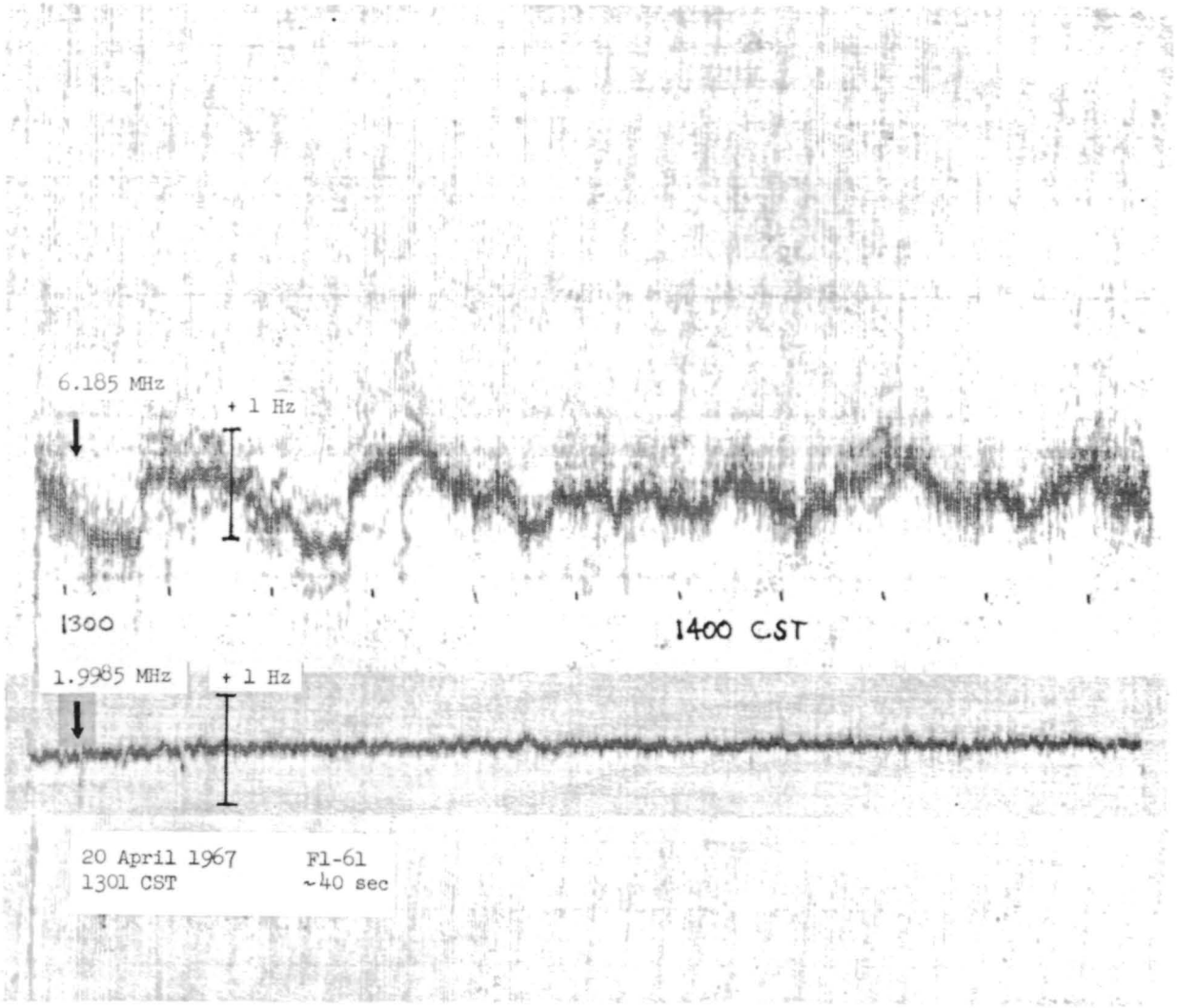


Figure 14: Doppler data record, 20 April 1967: Huntsville, Alabama

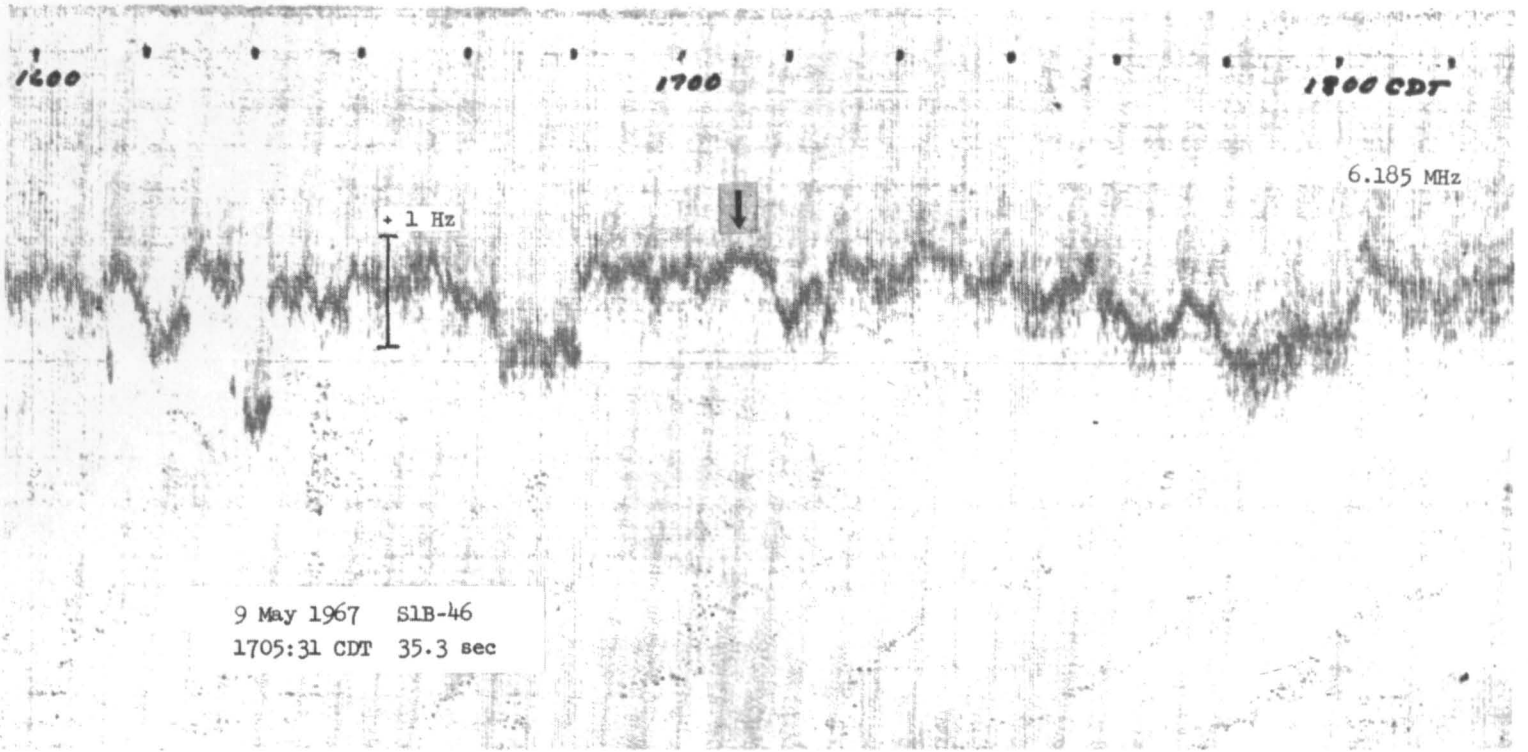


Figure 15: Doppler data record, 9 May 1967: Huntsville, Alabama

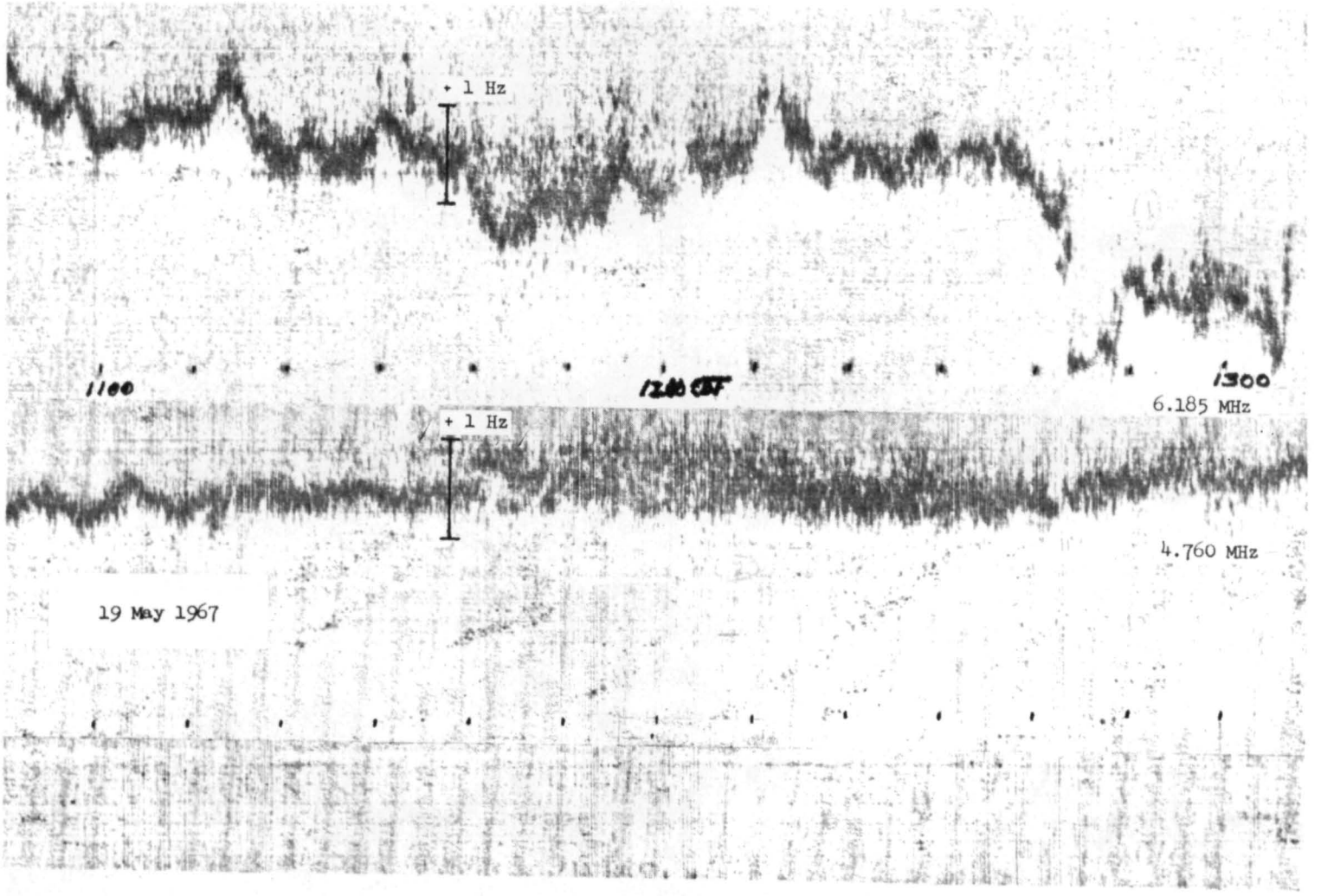


Figure 16 (a): Doppler data record, 19 May 1967: Huntsville, Alabama

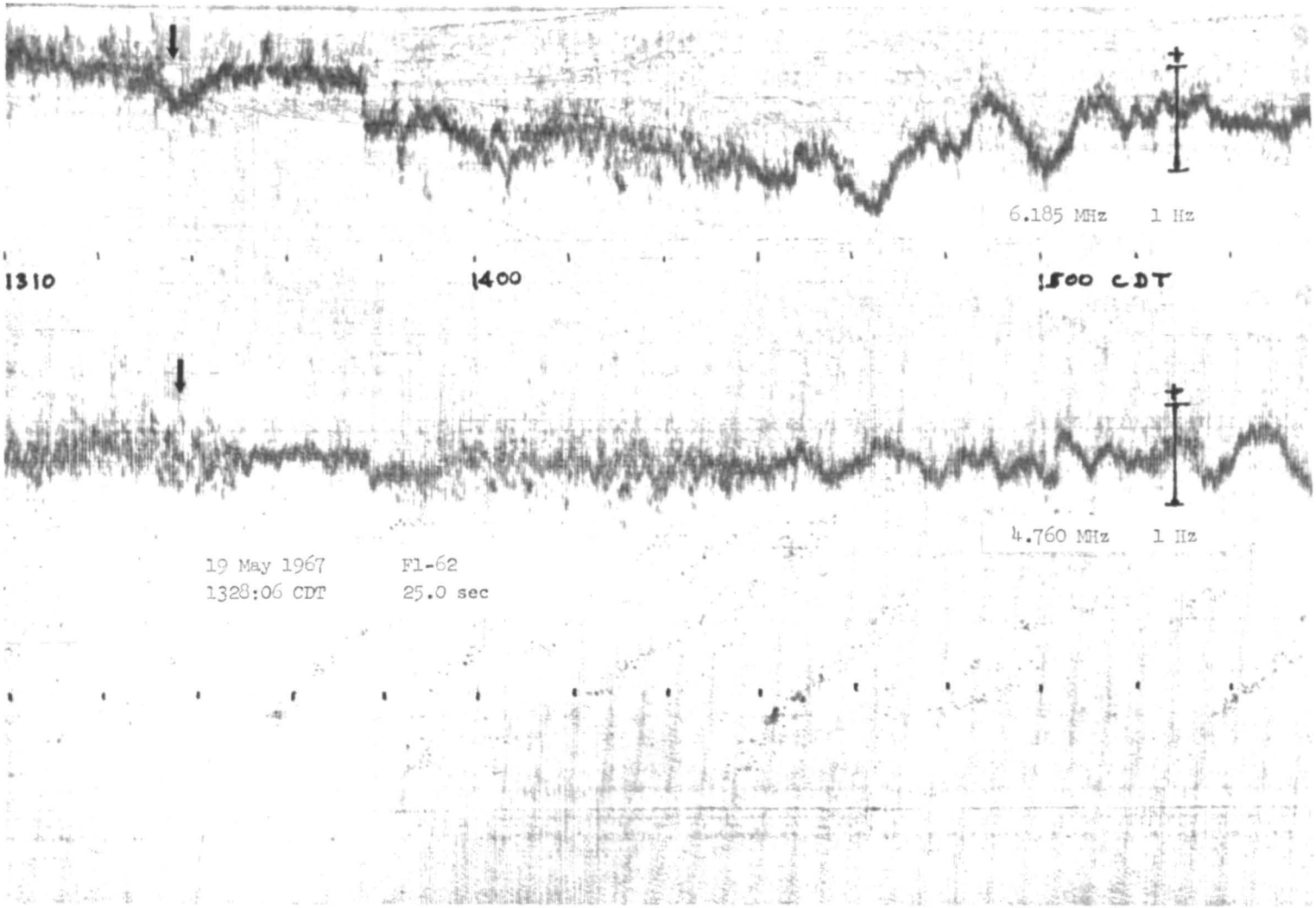


Figure 16 (b): Doppler data record, 19 May 1967: Huntsville, Alabama

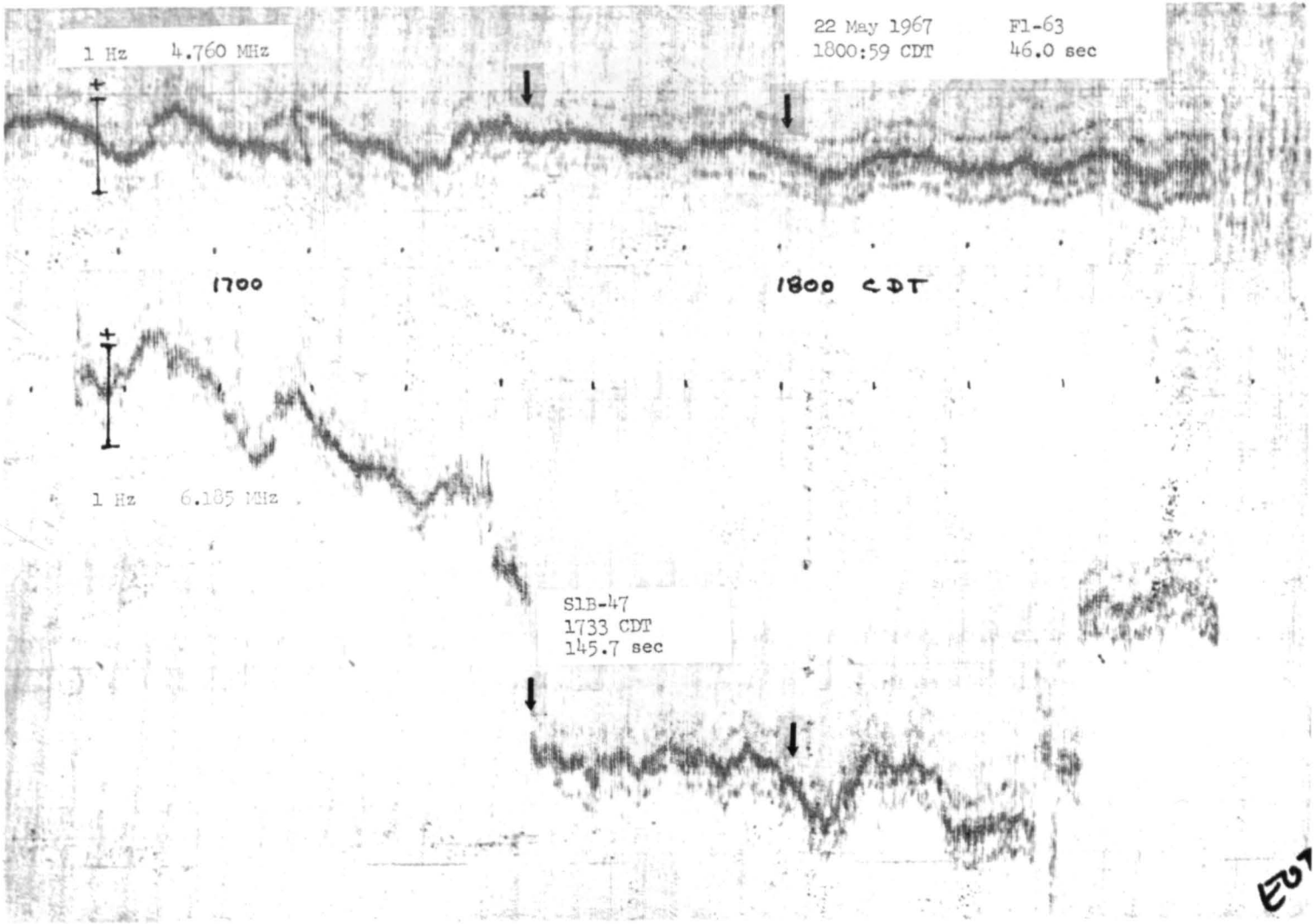


Figure 17: Doppler data record, 22 May 1967: Huntsville, Alabama

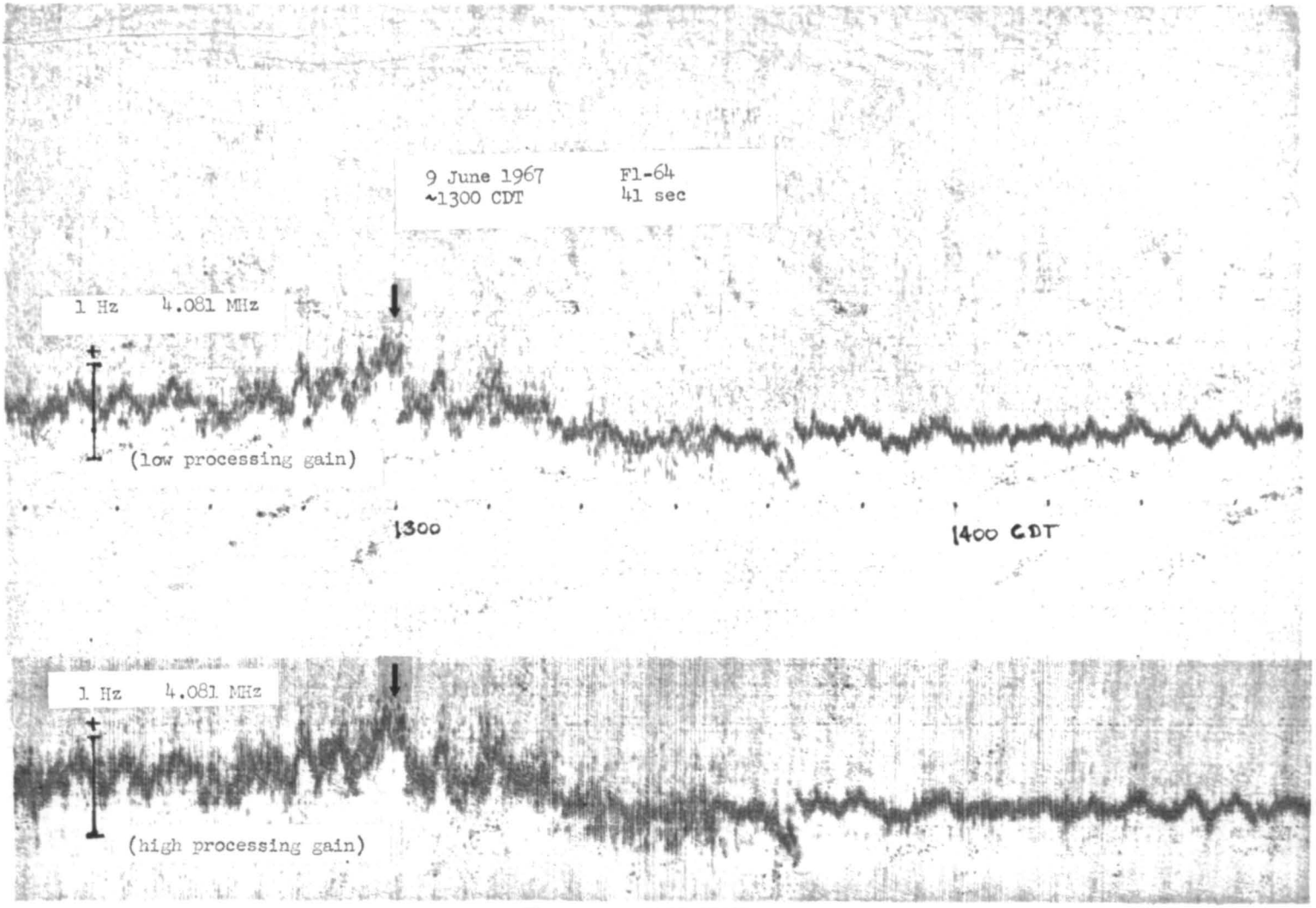


Figure 18: Doppler data record, 9 June 1967: Huntsville, Alabama

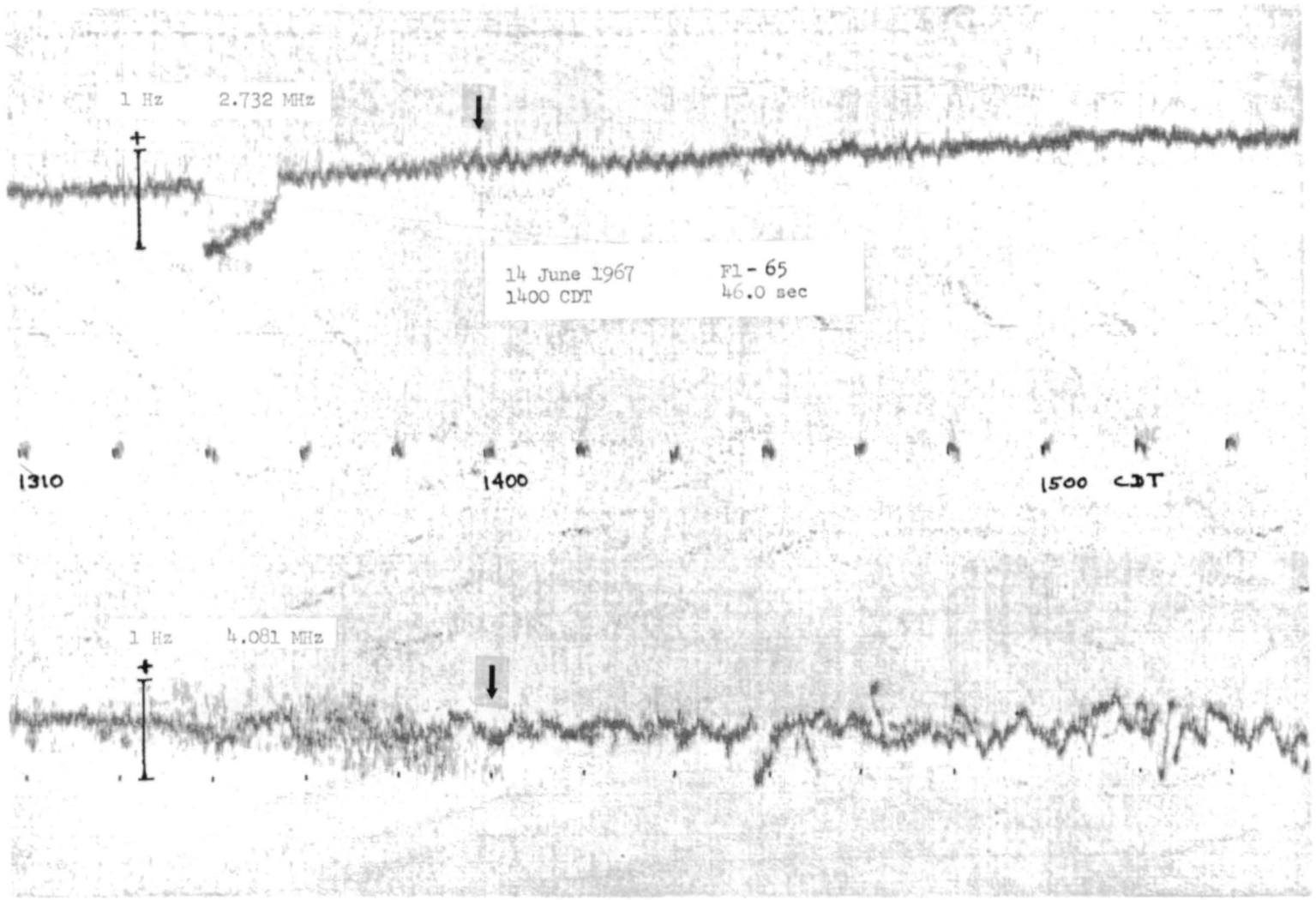


Figure 19: Doppler data record, 14 June 1967: Huntsville, Alabama

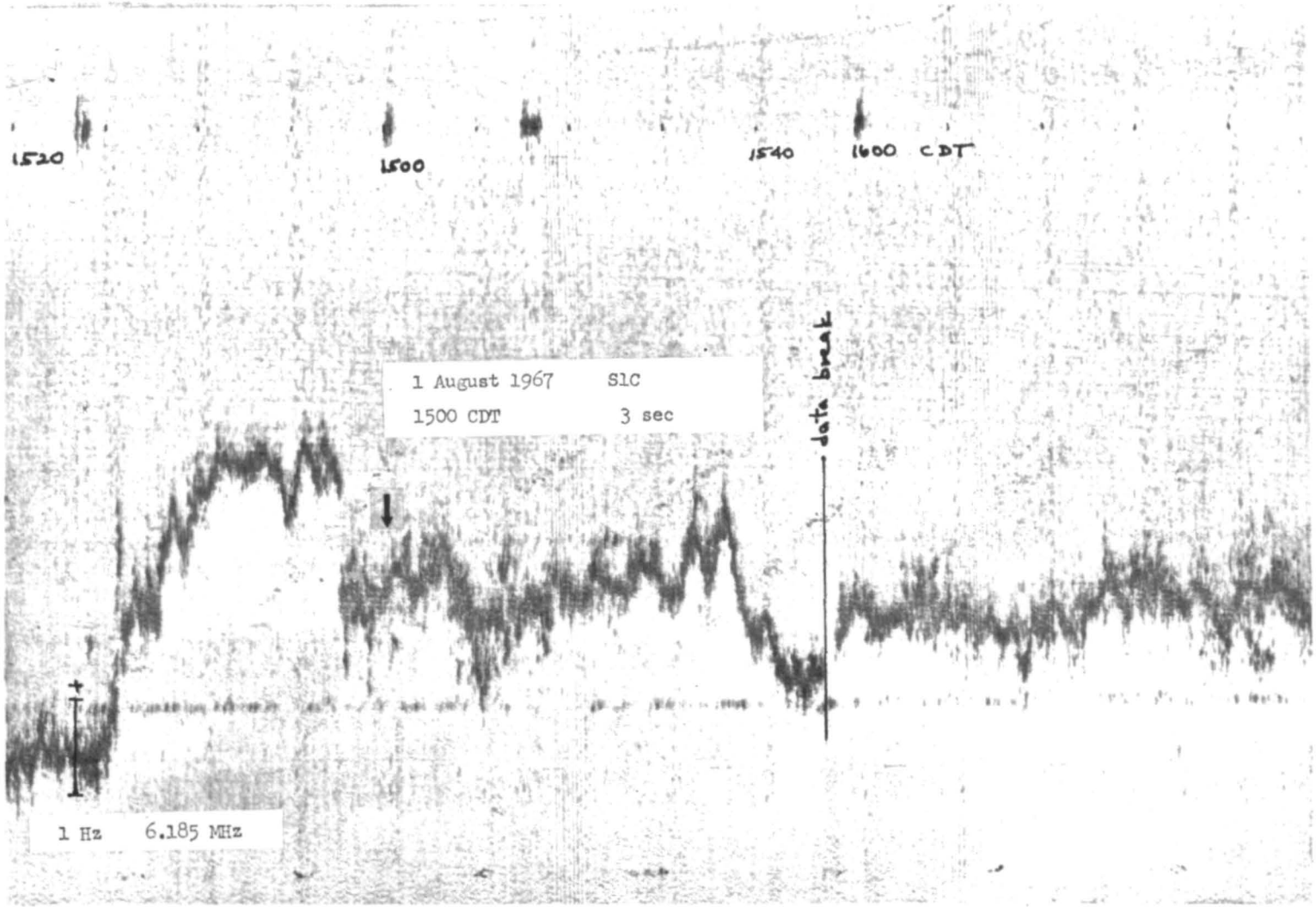


Figure 20: Doppler data record, 1 August 1967: Huntsville, Alabama

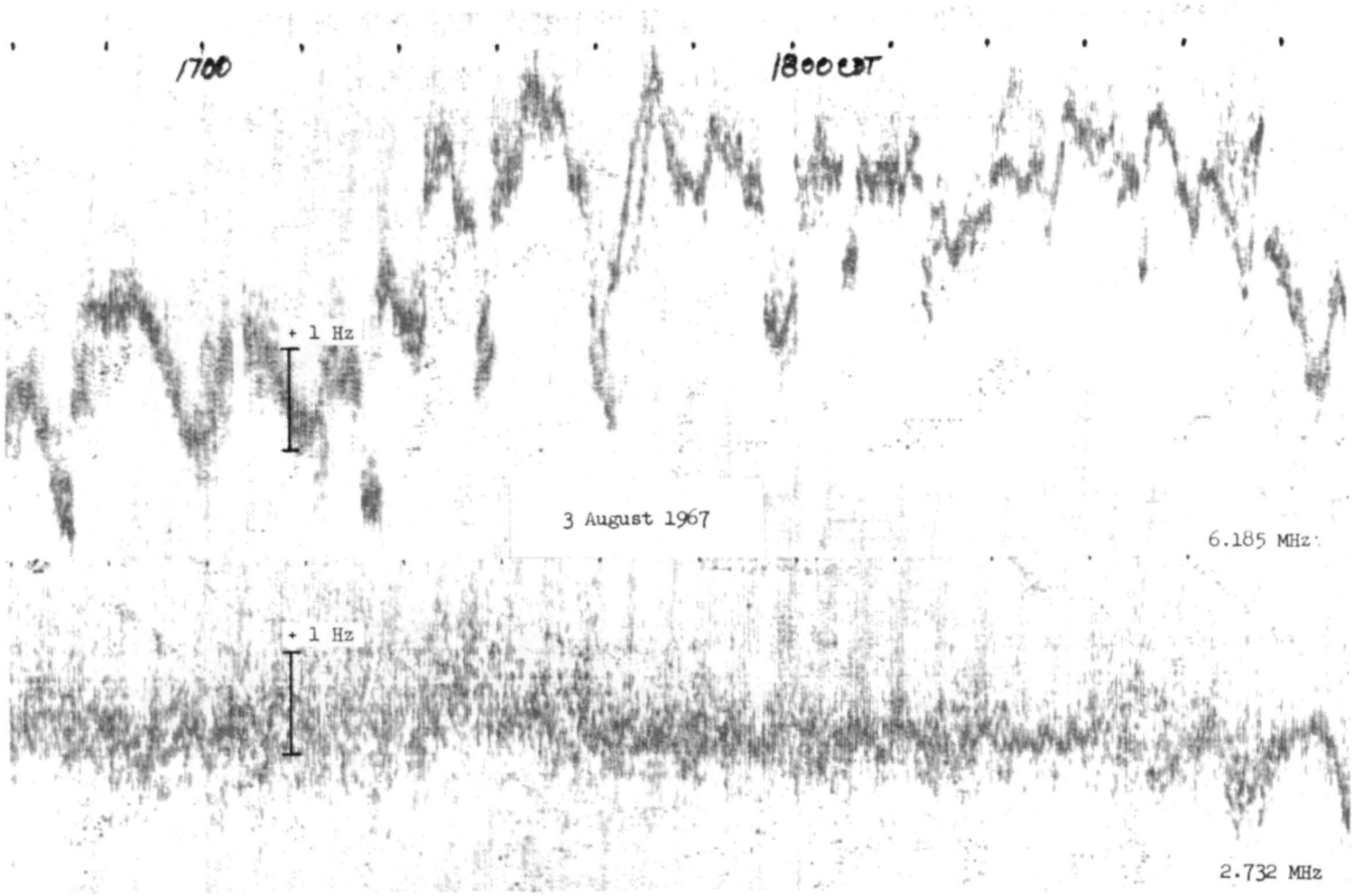


Figure 21 (a): Doppler data record, 3 August 1967: Huntsville, Alabama

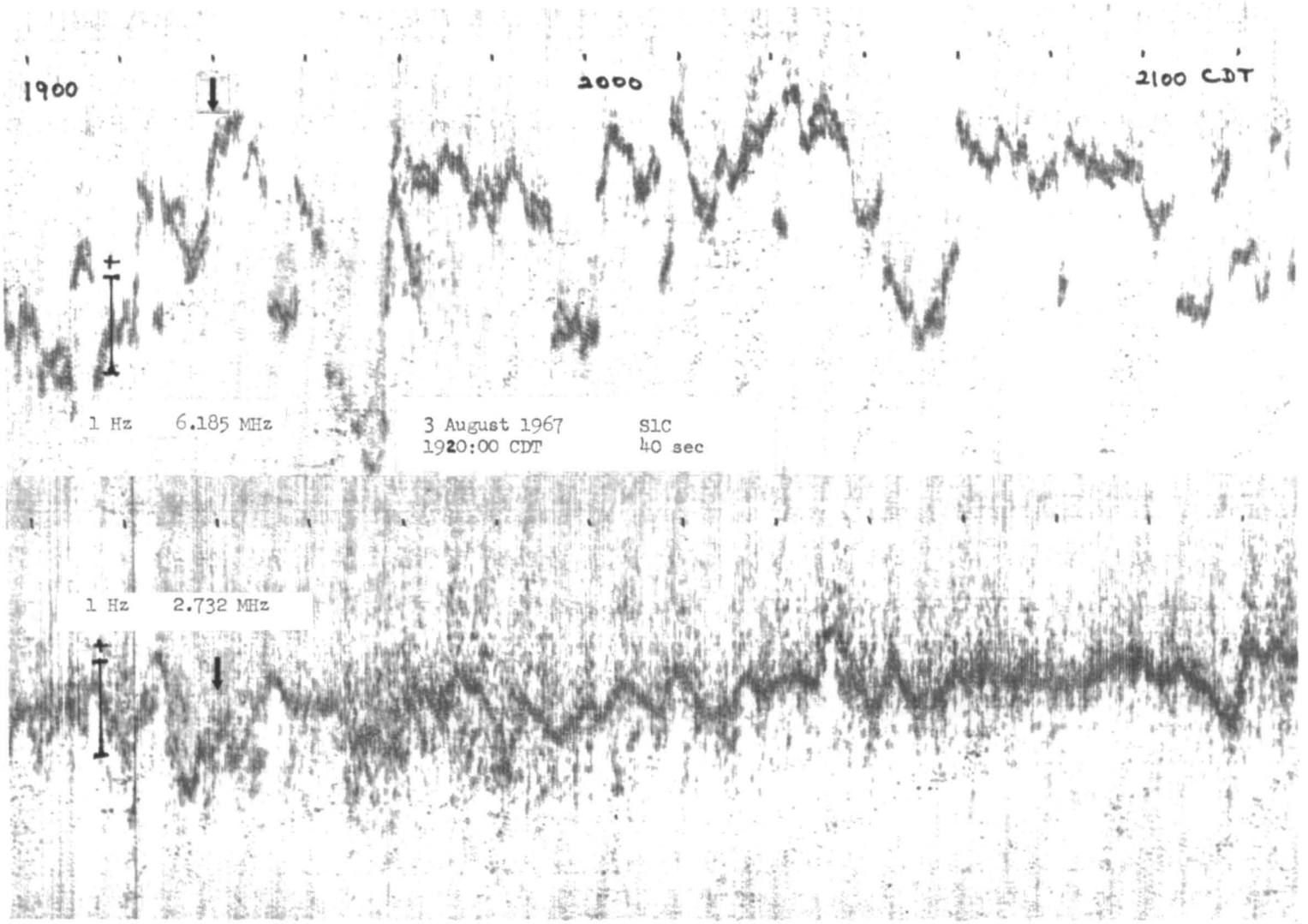


Figure 21 (b): Doppler data record, 3 August 1967: Huntsville, Alabama

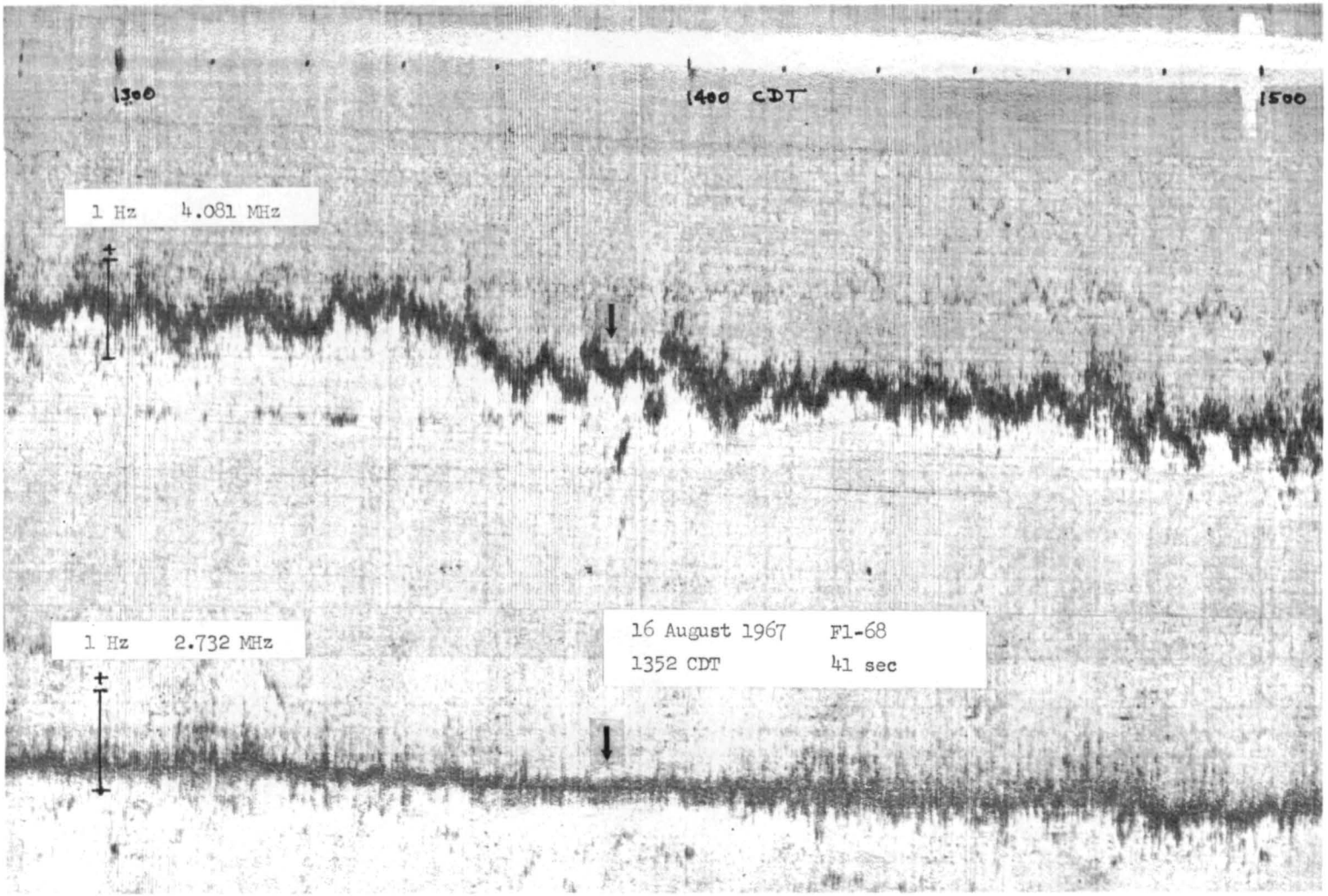


Figure 22: Doppler data record, 16 August 1967: Huntsville, Alabama

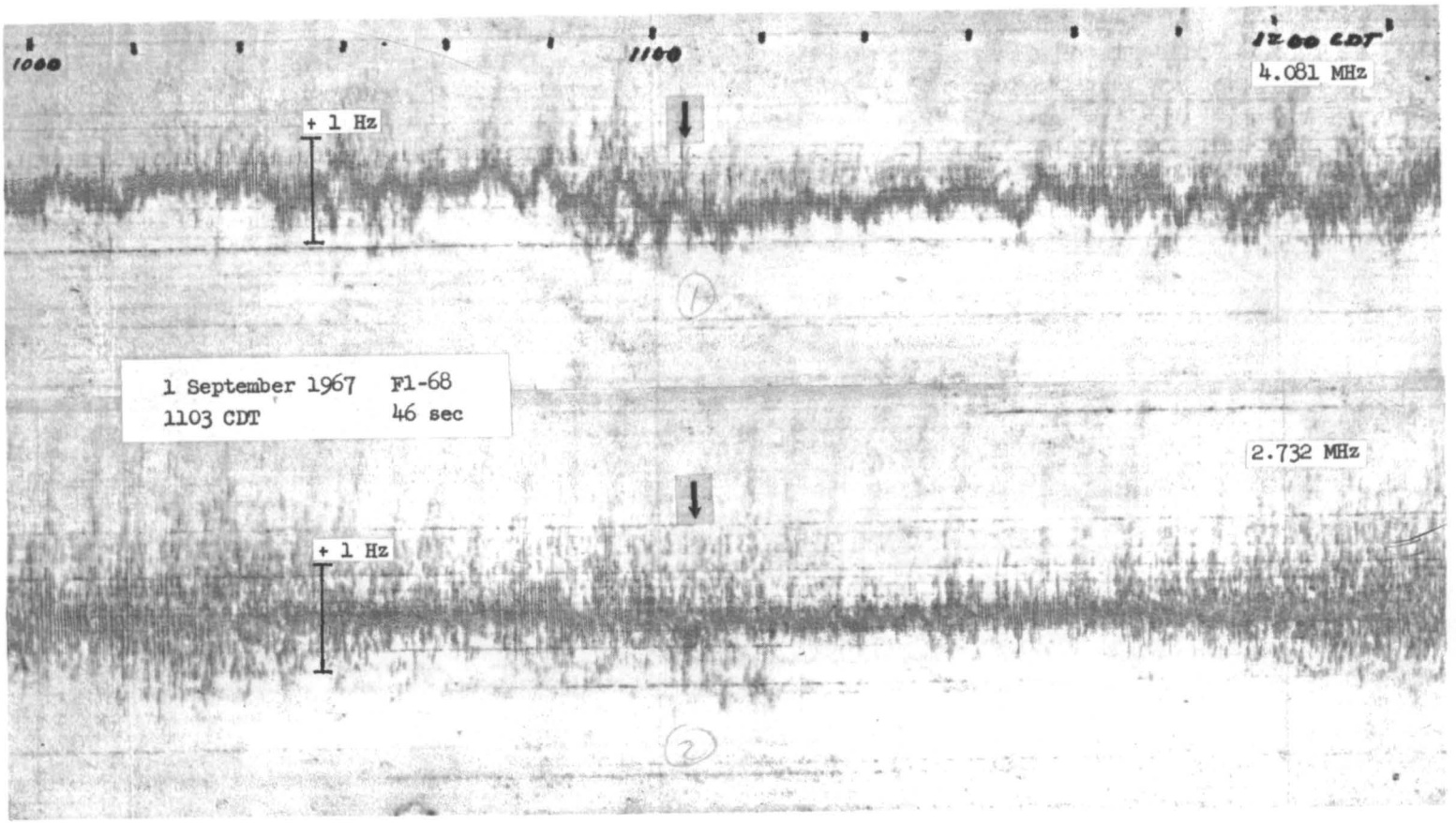


Figure 23: Doppler data record, 1 September 1967: Huntsville, Alabama

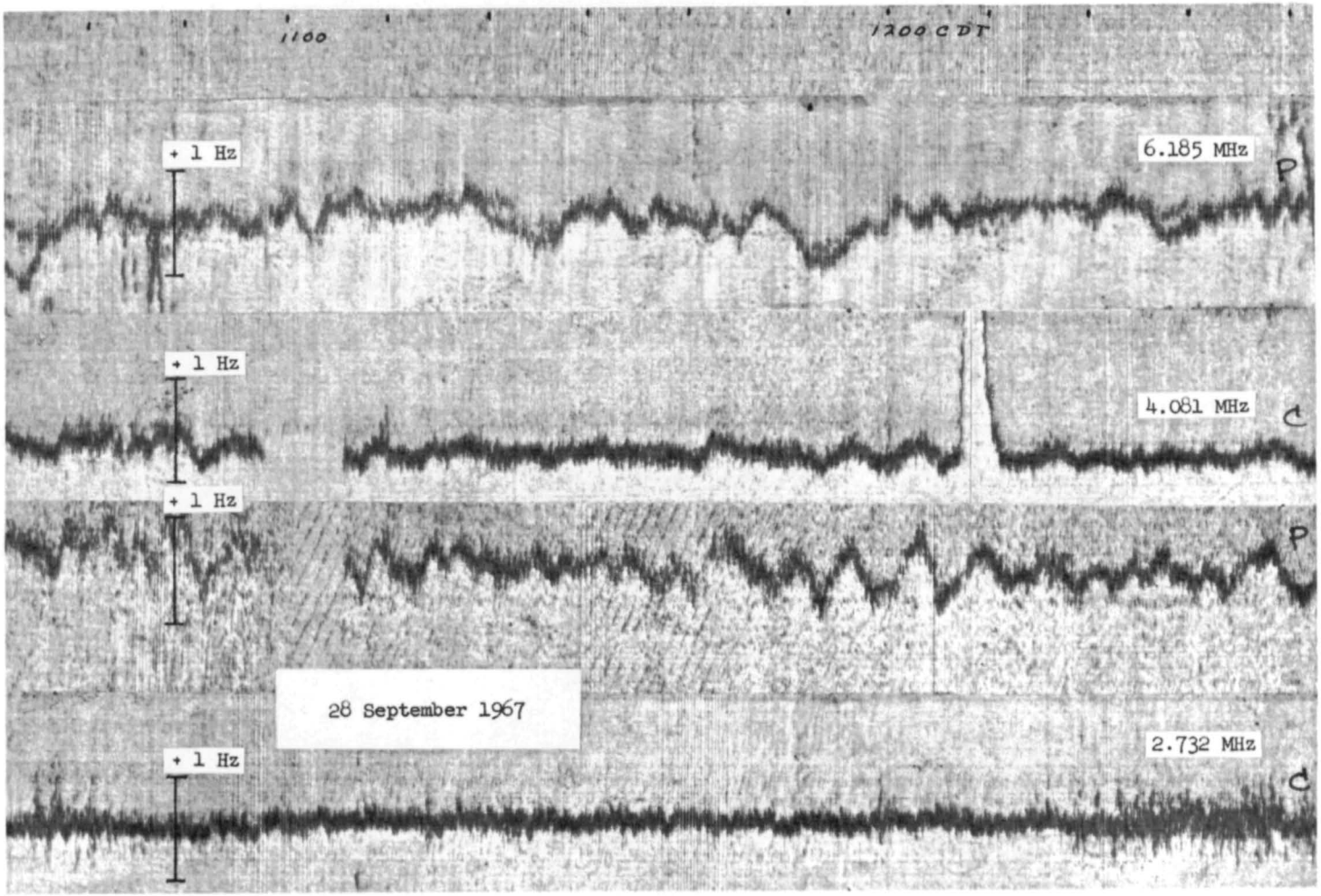


Figure 24 (a): Doppler data record, 28 September 1967: Huntsville, Alabama

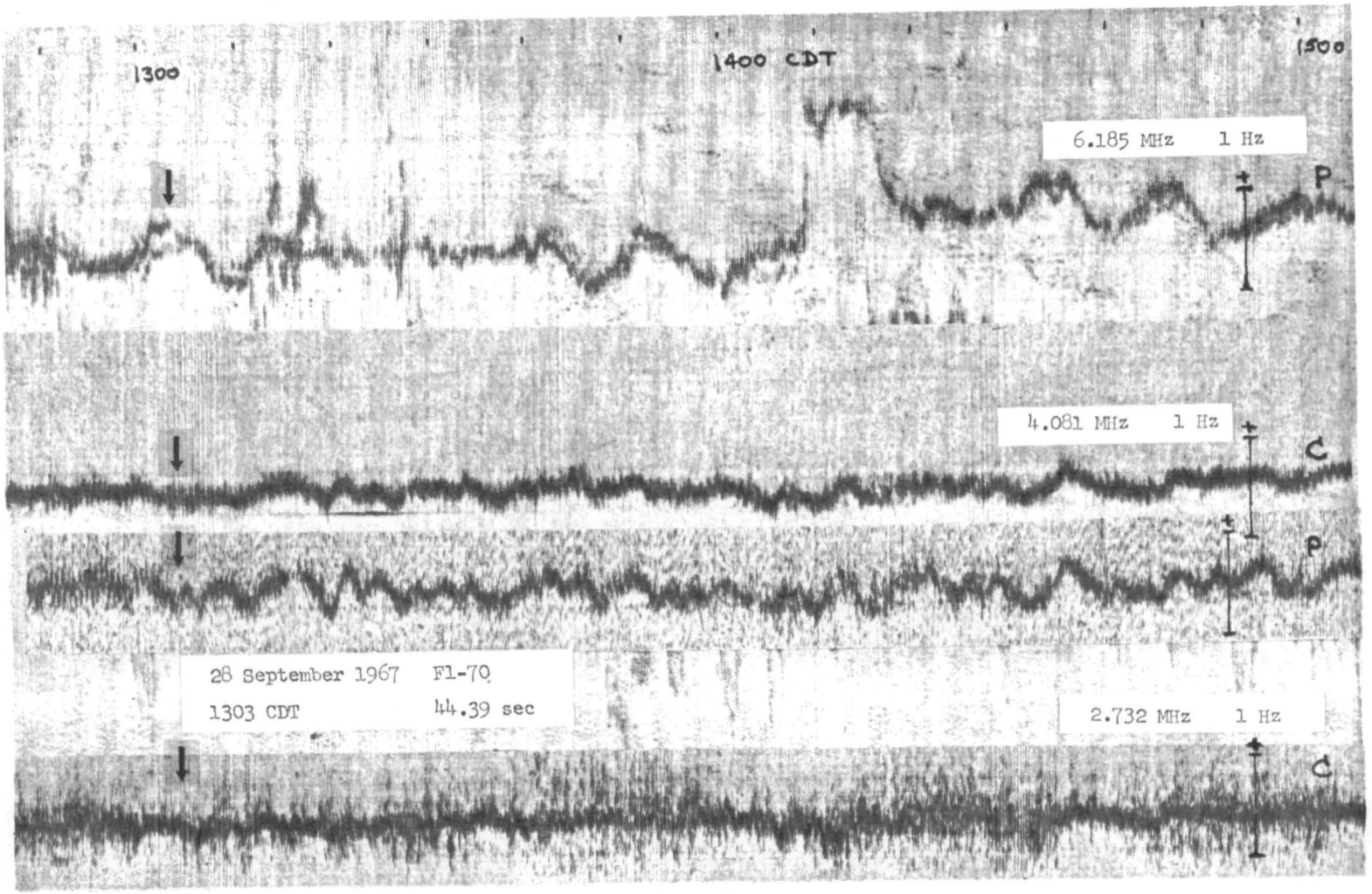


Figure 24 (b): Doppler data record, 28 September 1967: Huntsville, Alabama

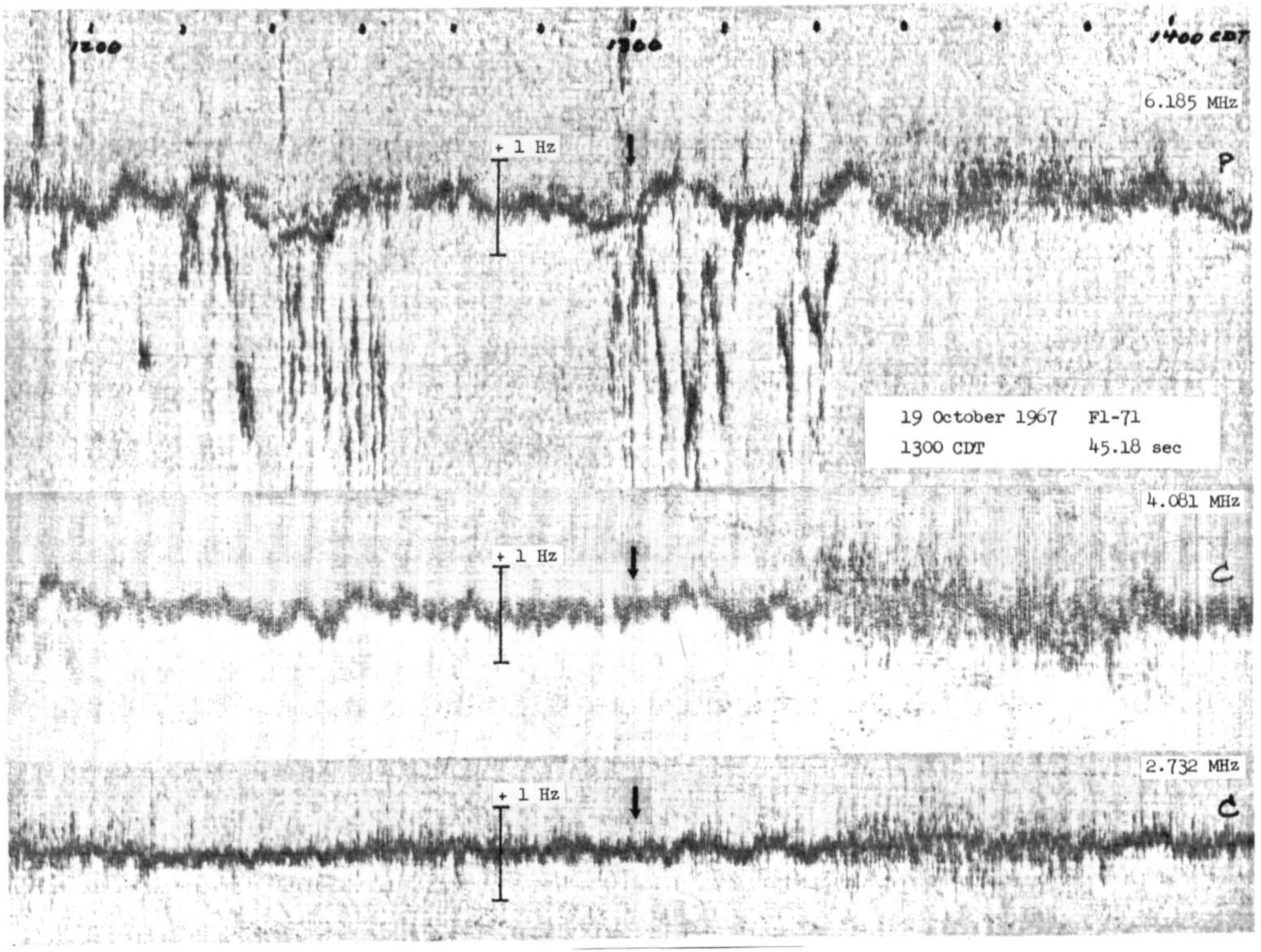


Figure 25: Doppler data record, 19 October 1967: Huntsville, Alabama

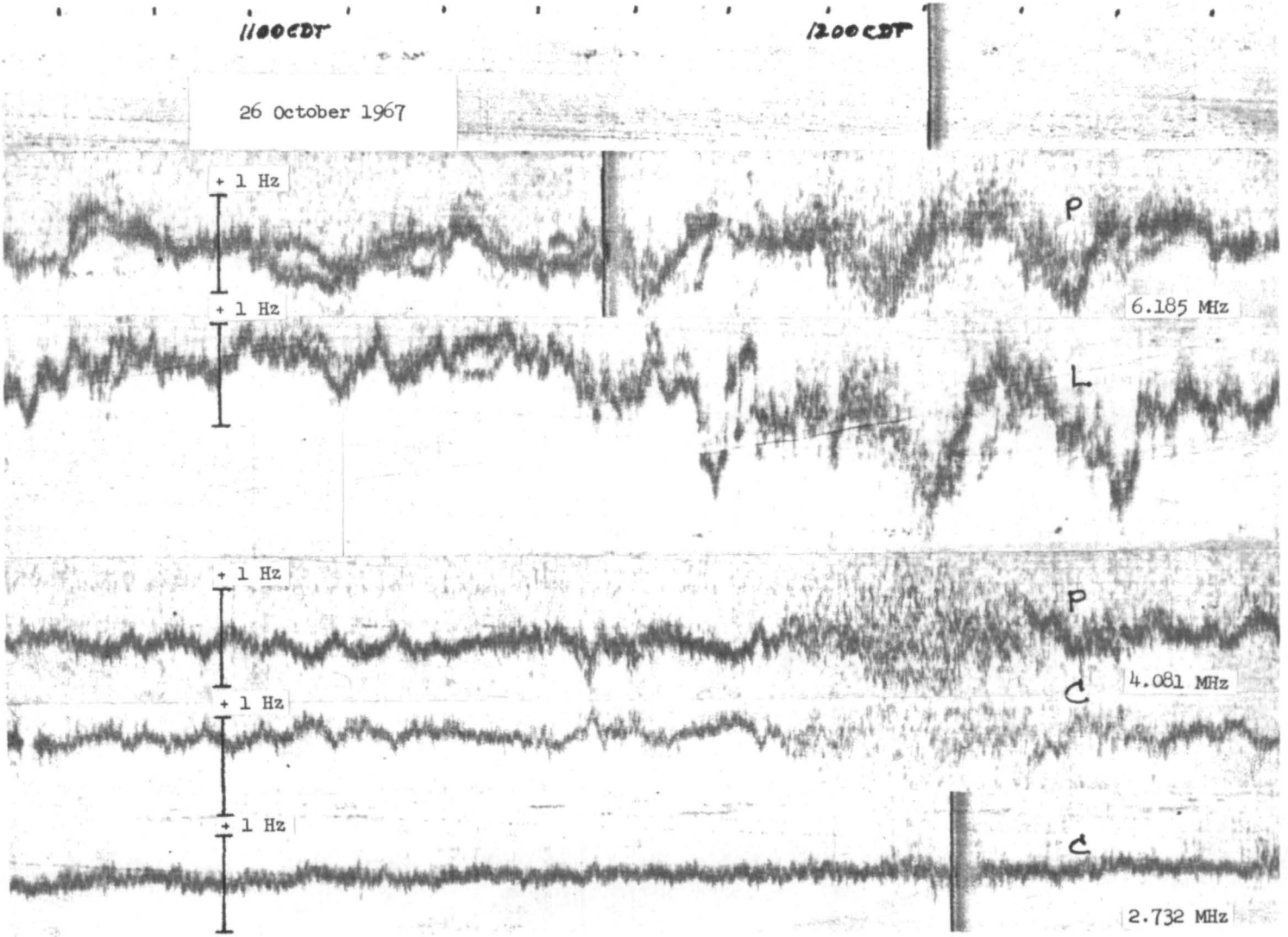


Figure 26 (a): Doppler data record, 26 October 1967: Huntsville, Alabama

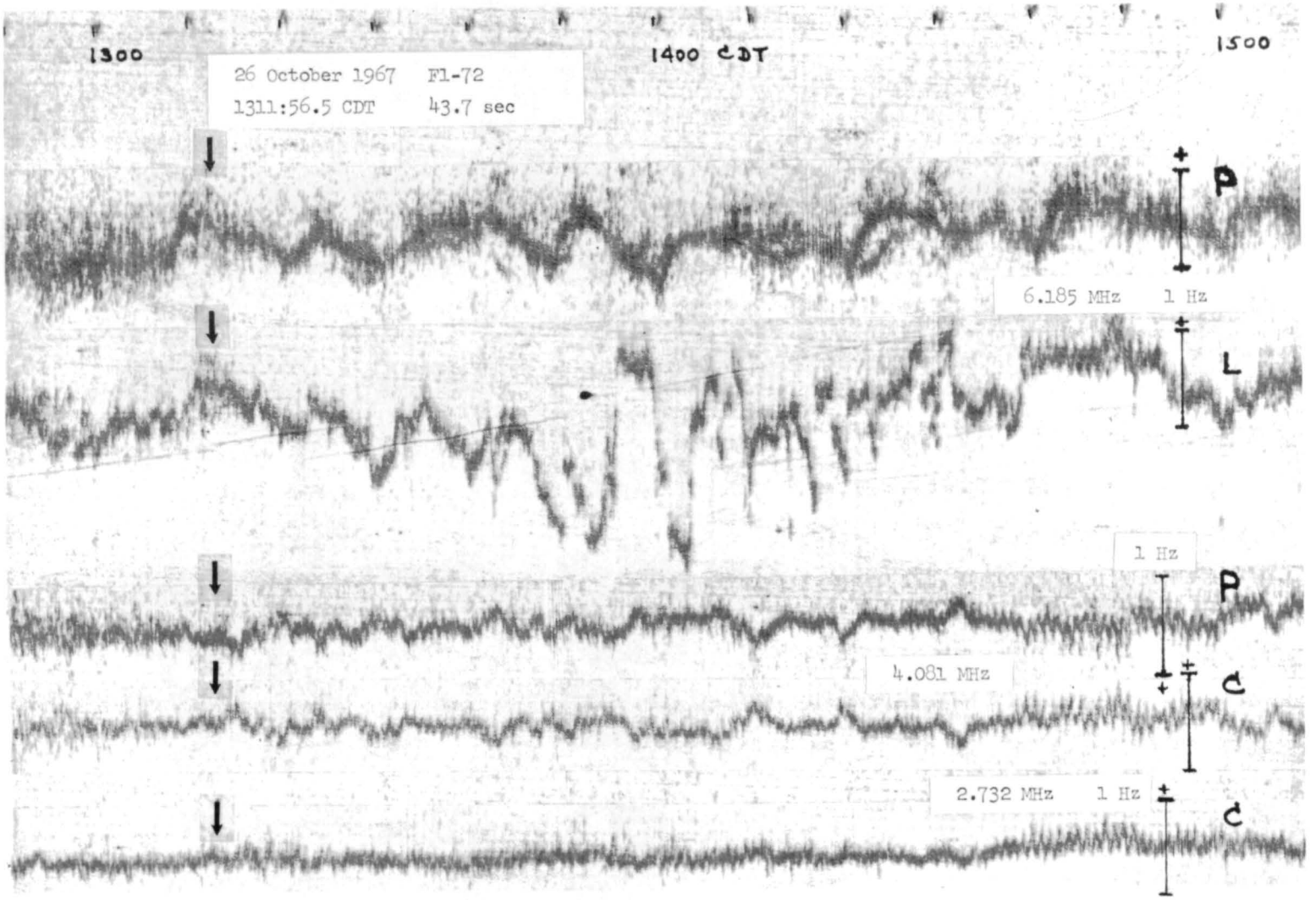


Figure 26 (b): Doppler data record, 26 October 1967: Huntsville, Alabama

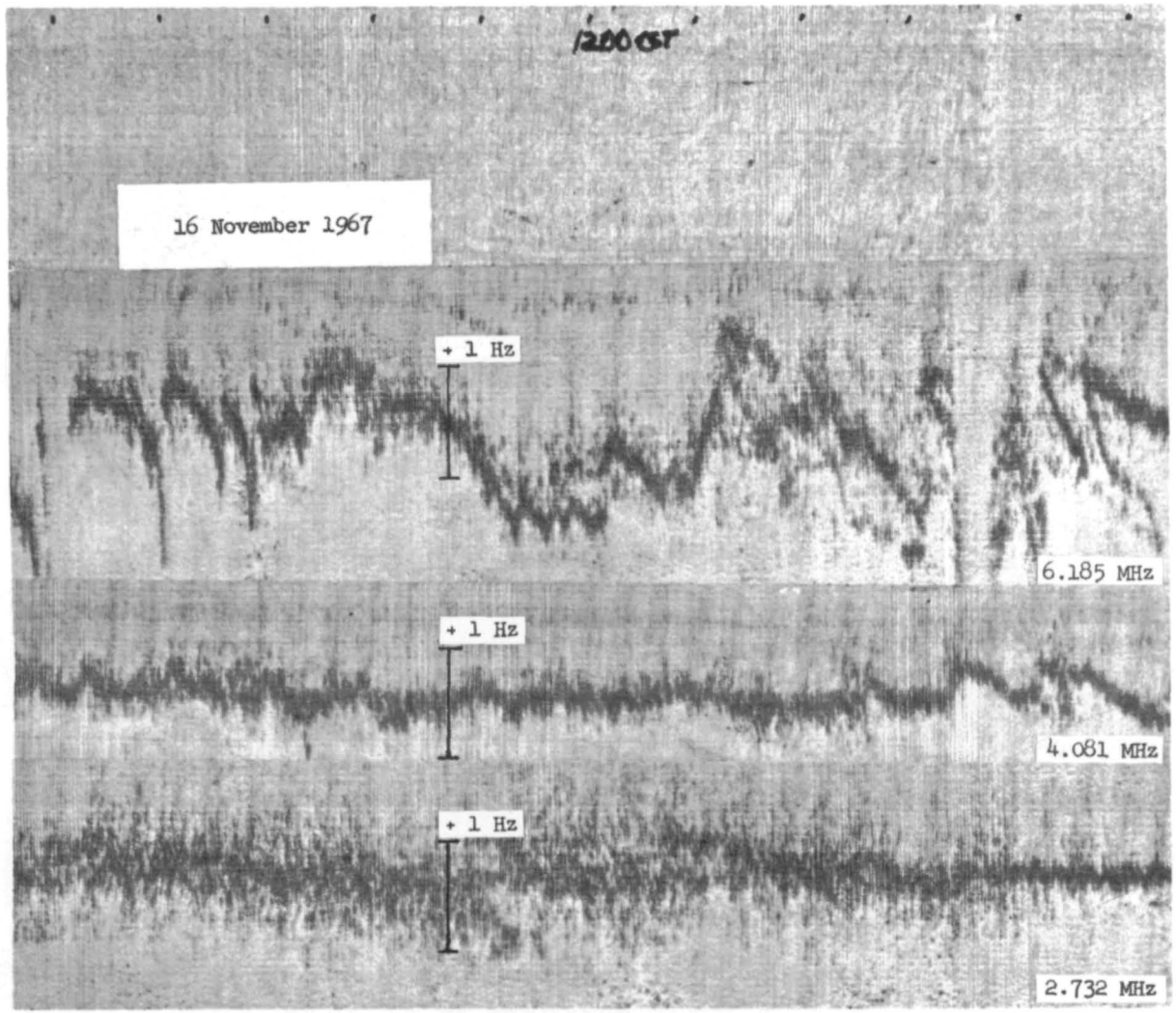


Figure 27 (a): Doppler data record, 16 November 1967: Huntsville, Alabama

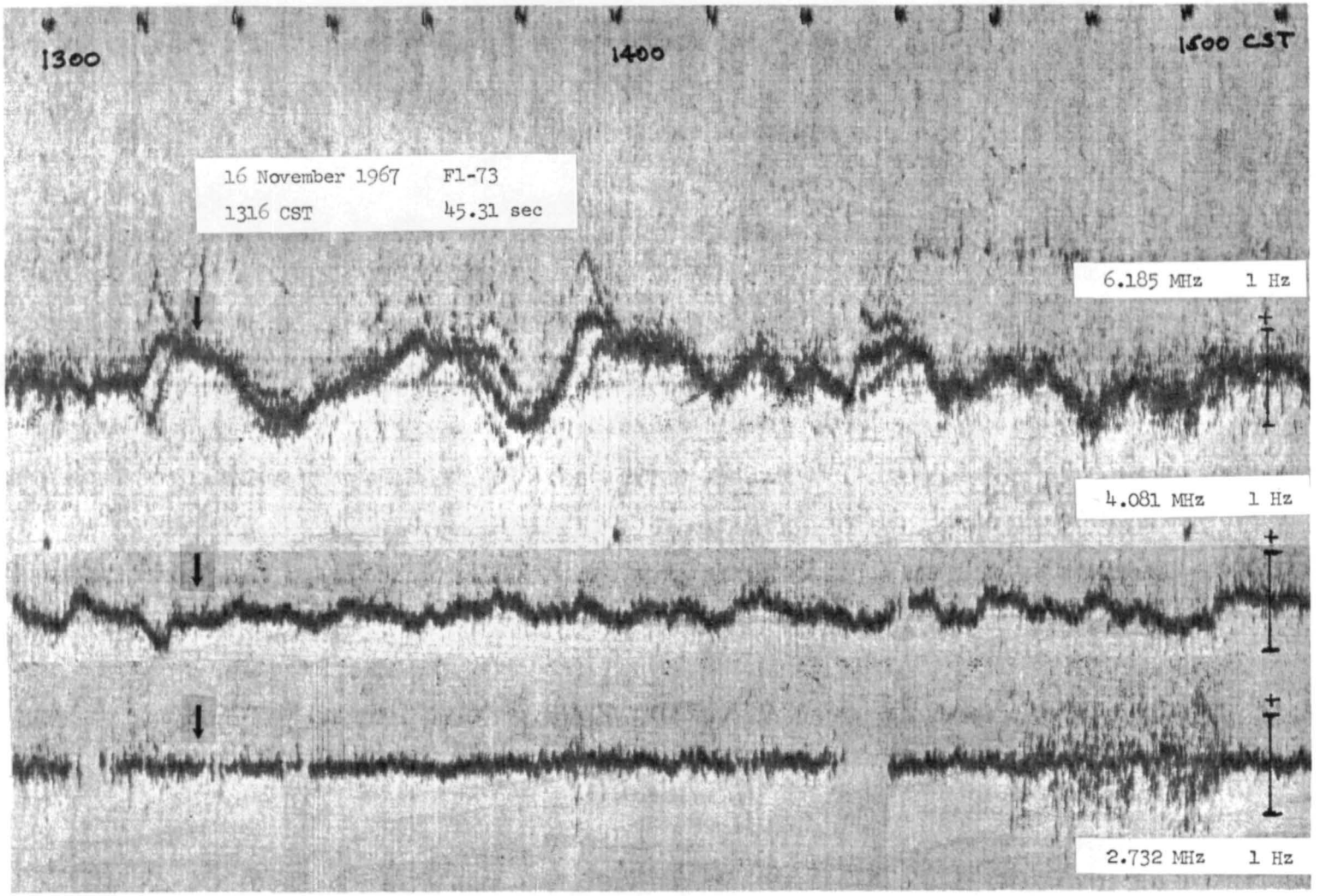


Figure 27 (b): Doppler data record, 16 November 1967: Huntsville, Alabama

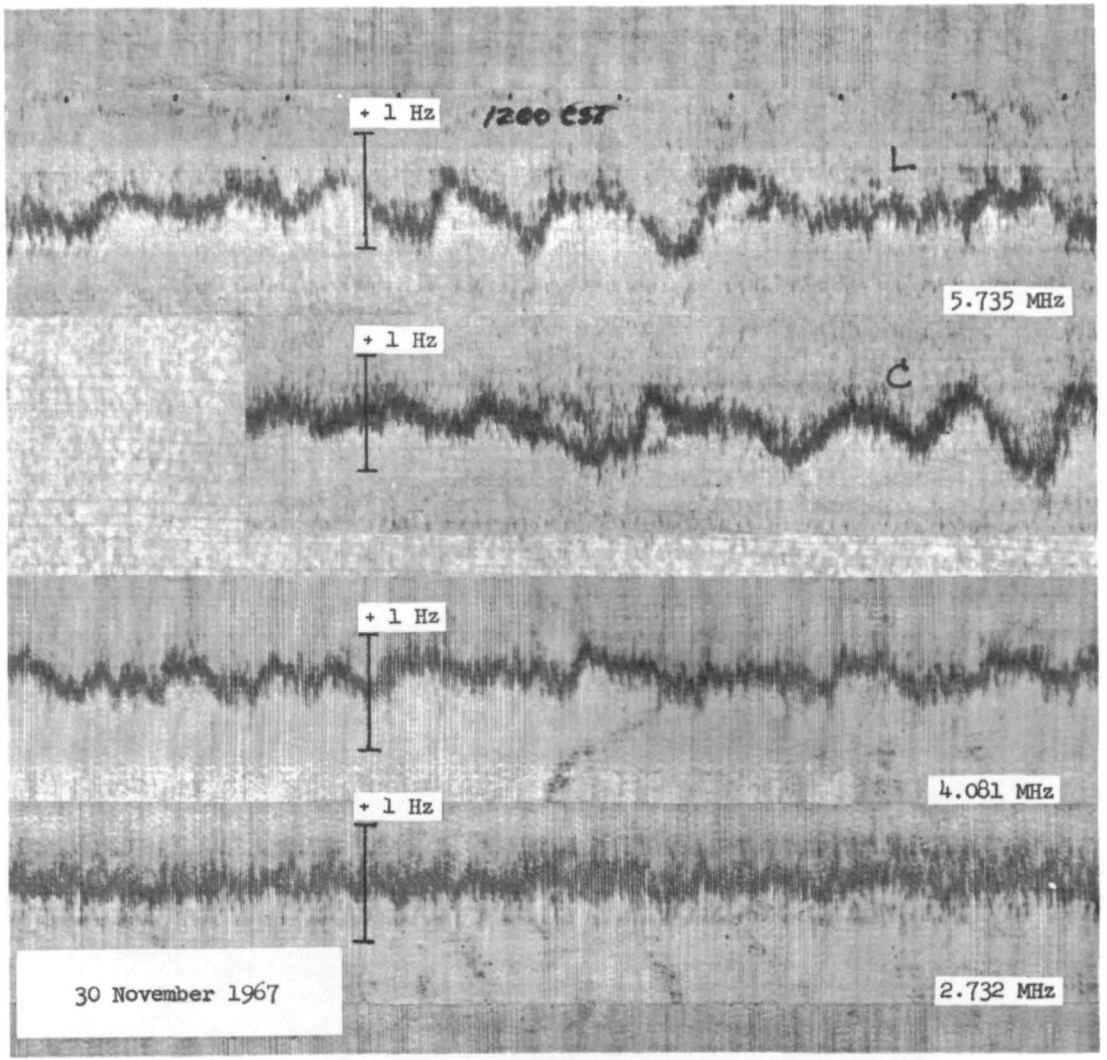


Figure 28 (a): Doppler data record, 30 November 1967: Huntsville, Alabama

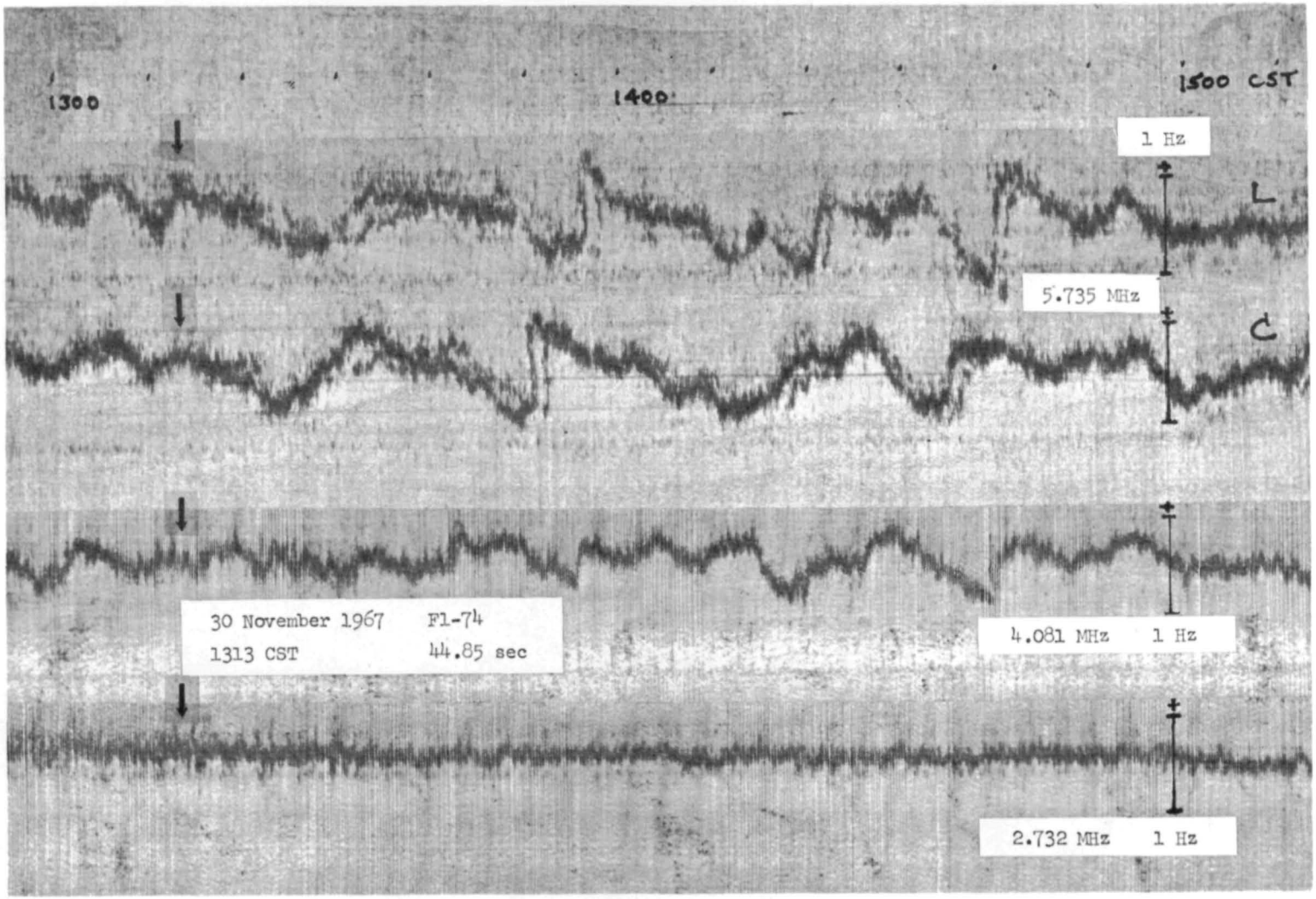


Figure 28 (b): Doppler data record, 30 November 1967: Huntsville, Alabama

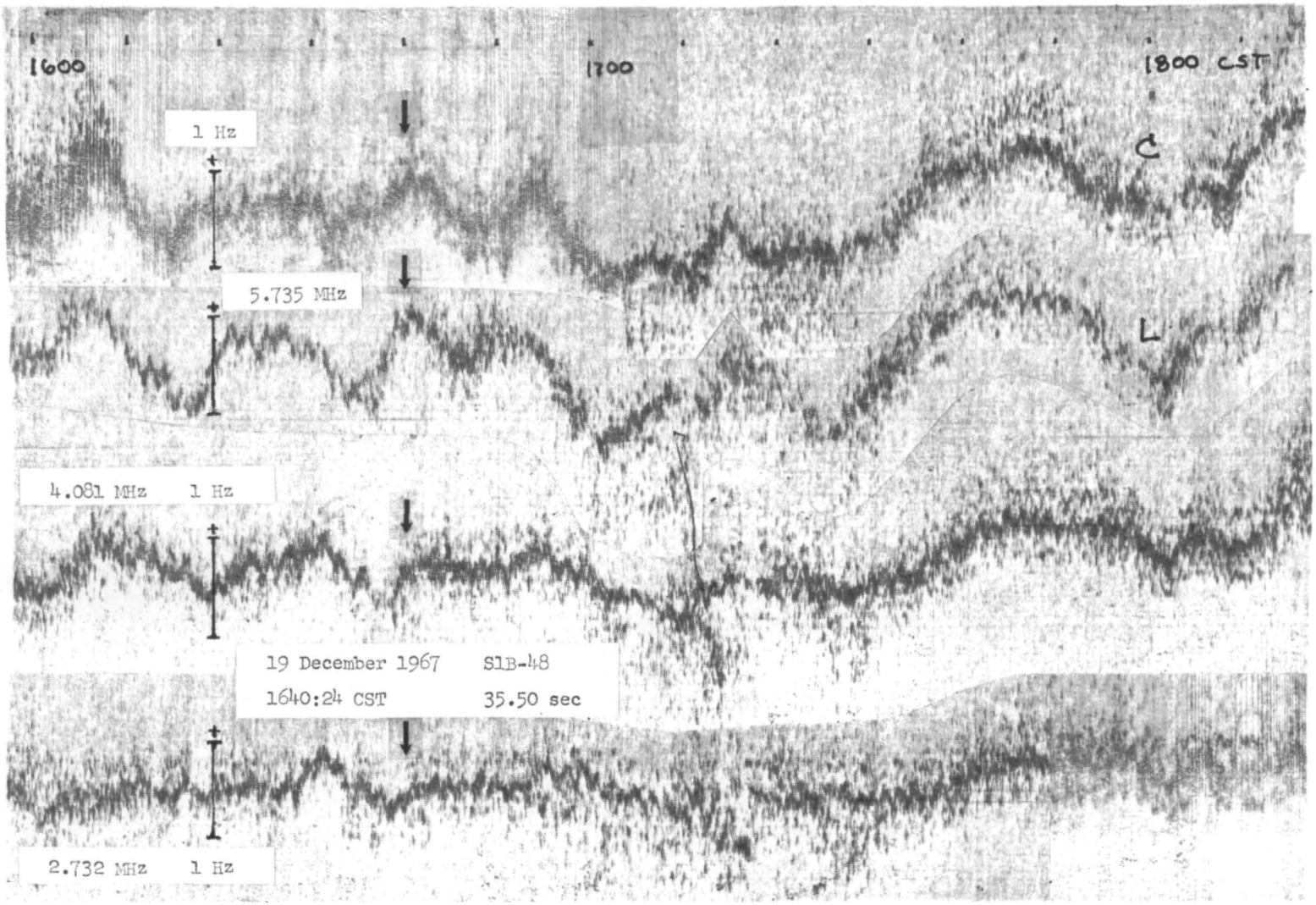


Figure 29: Doppler data record, 19 December 1967: Huntsville, Alabama

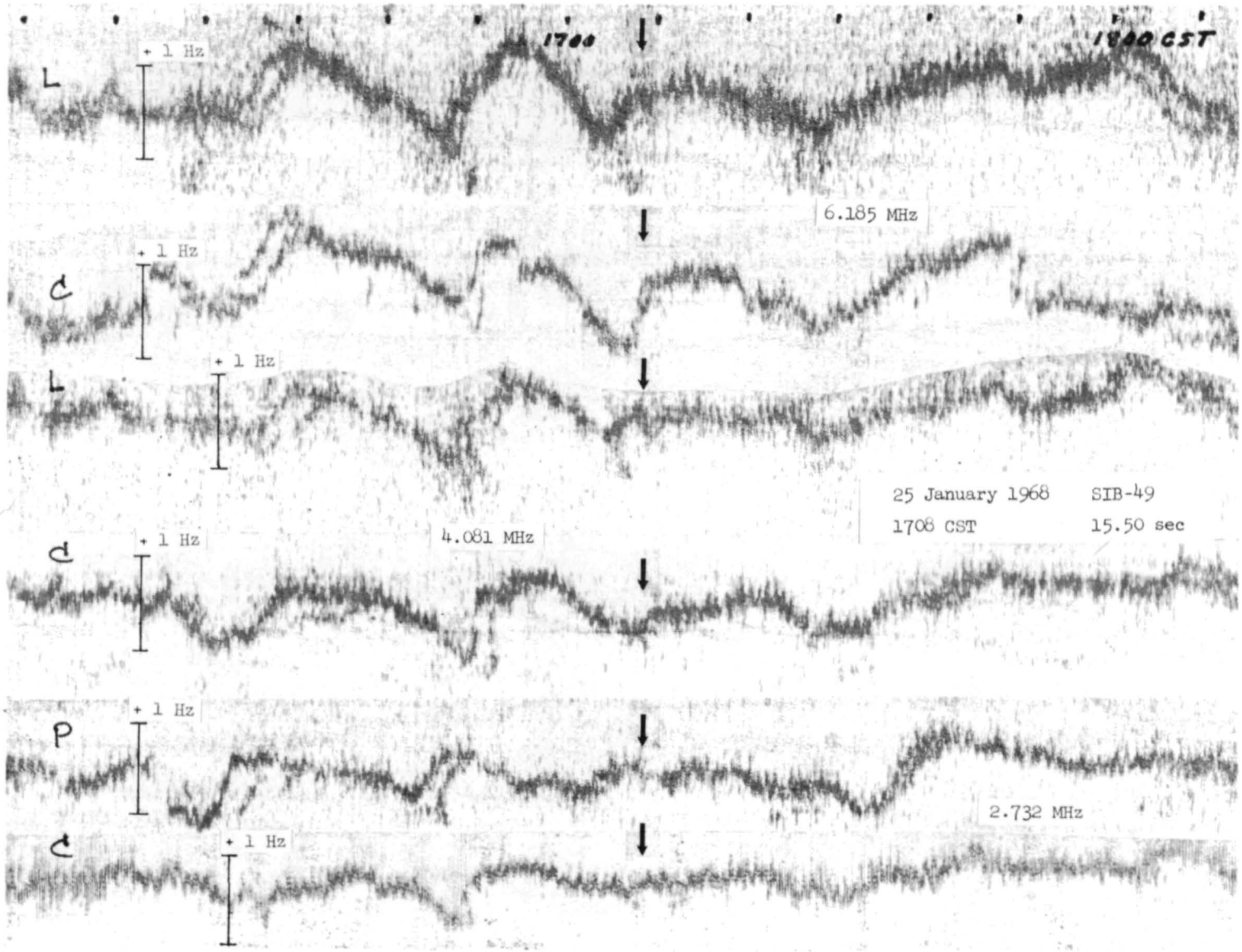


Figure 30: Doppler data record, 25 January 1968: Huntsville, Alabama

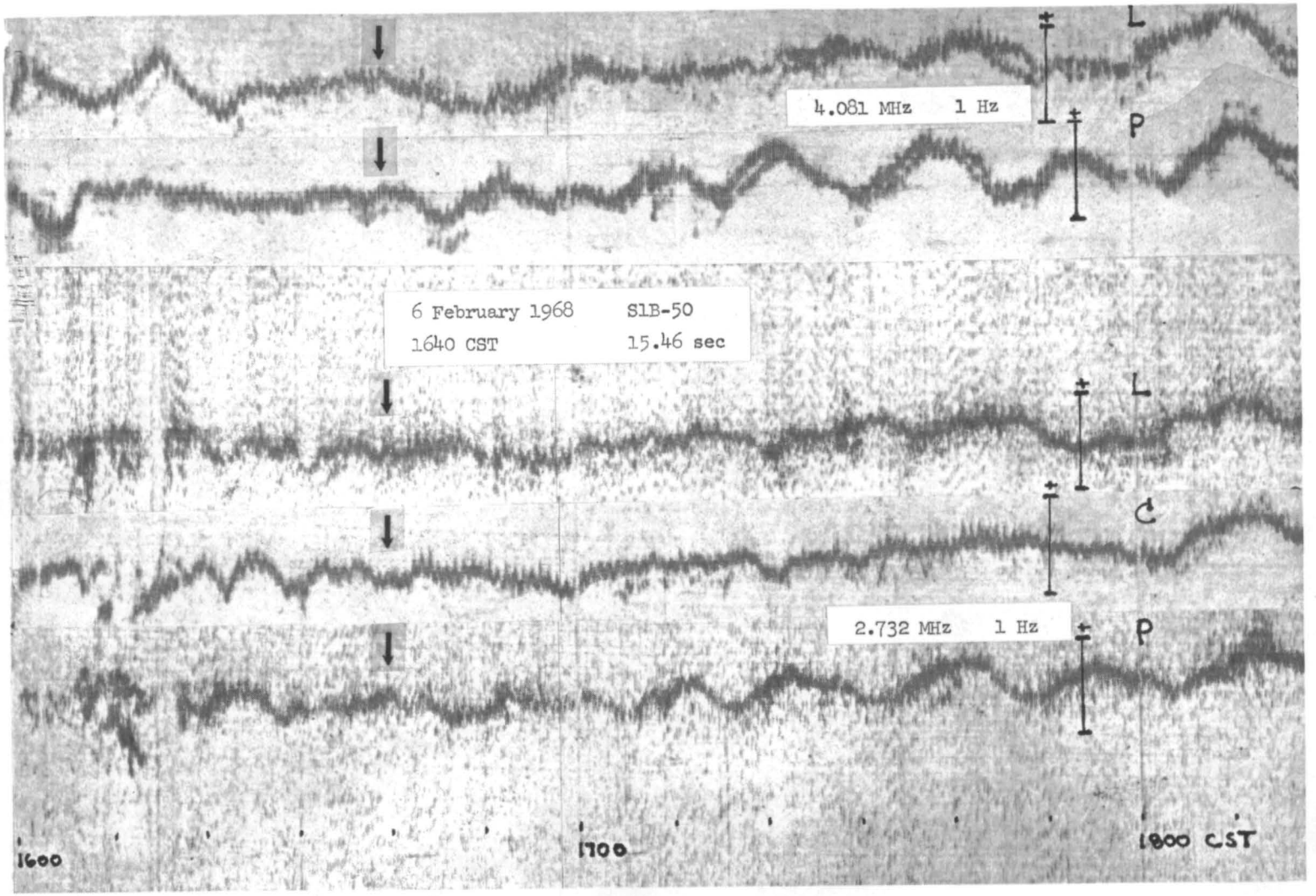


Figure 31 (a): Doppler data record, 6 February 1968: Huntsville, Alabama

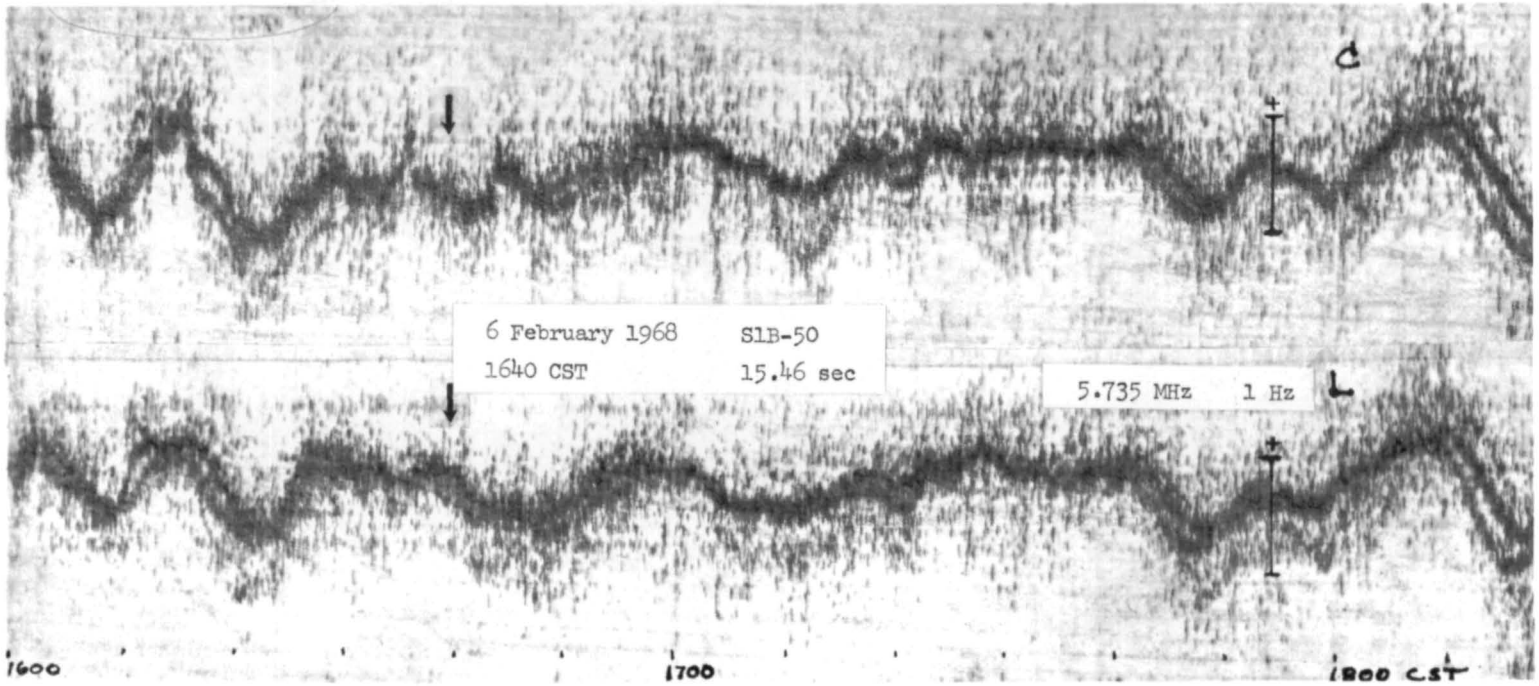


Figure 31 (b): Doppler data record, 6 February 1968: Huntsville, Alabama

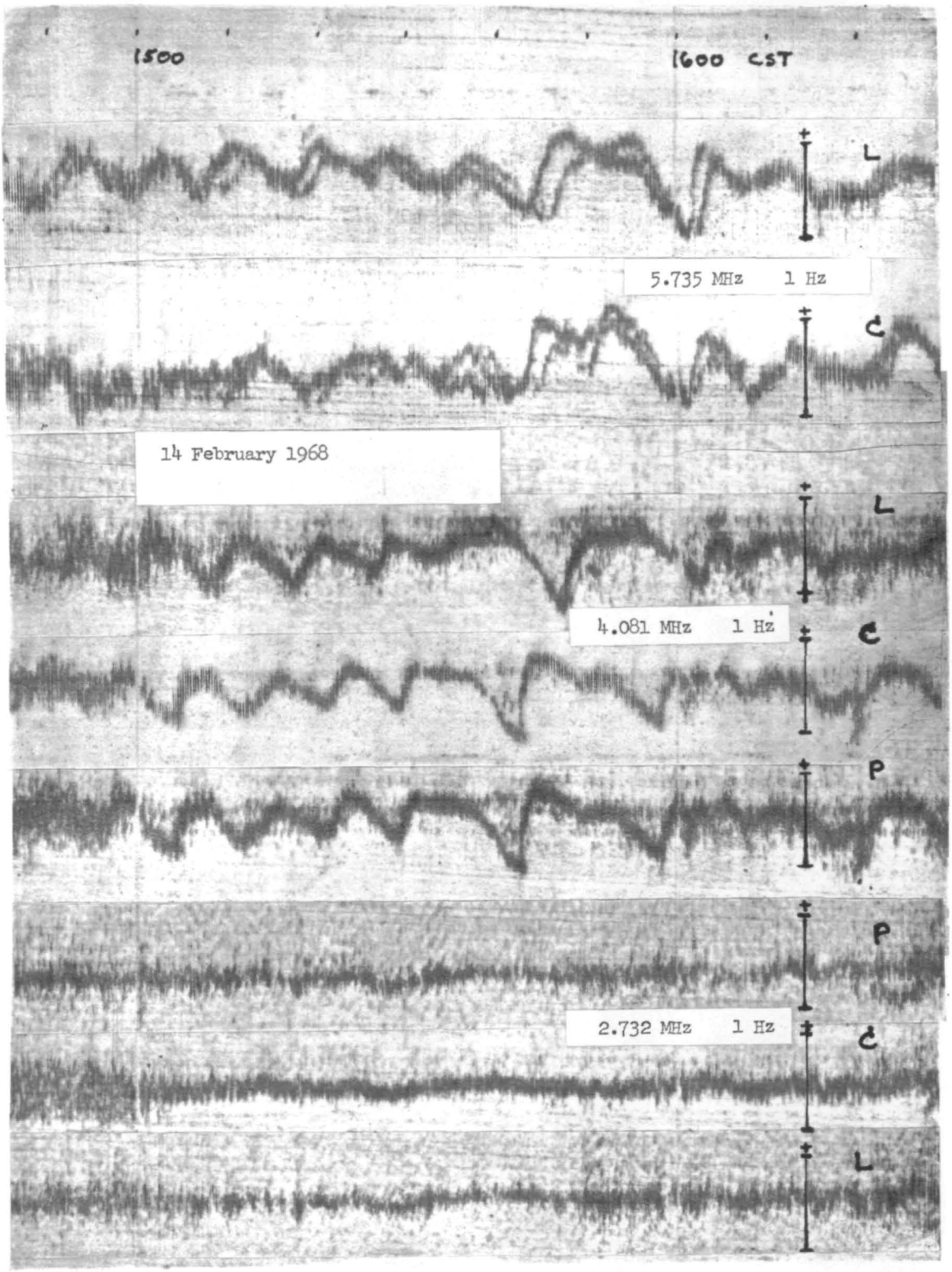


Figure 32 (a): Doppler data record,
14 February 1968: Huntsville, Alabama

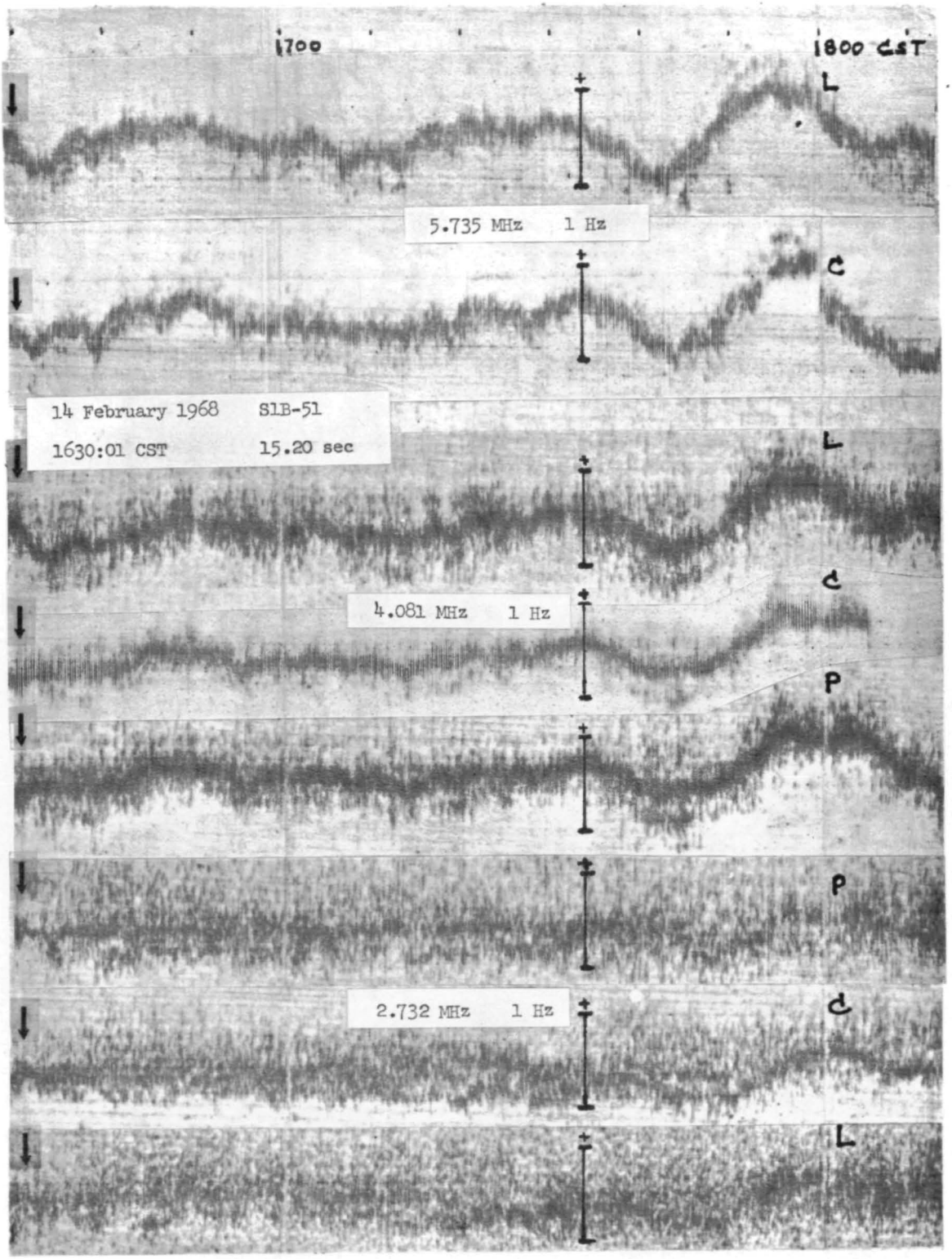


Figure 32 (b): Doppler data record,
14 February 1968: Huntsville, Alabama

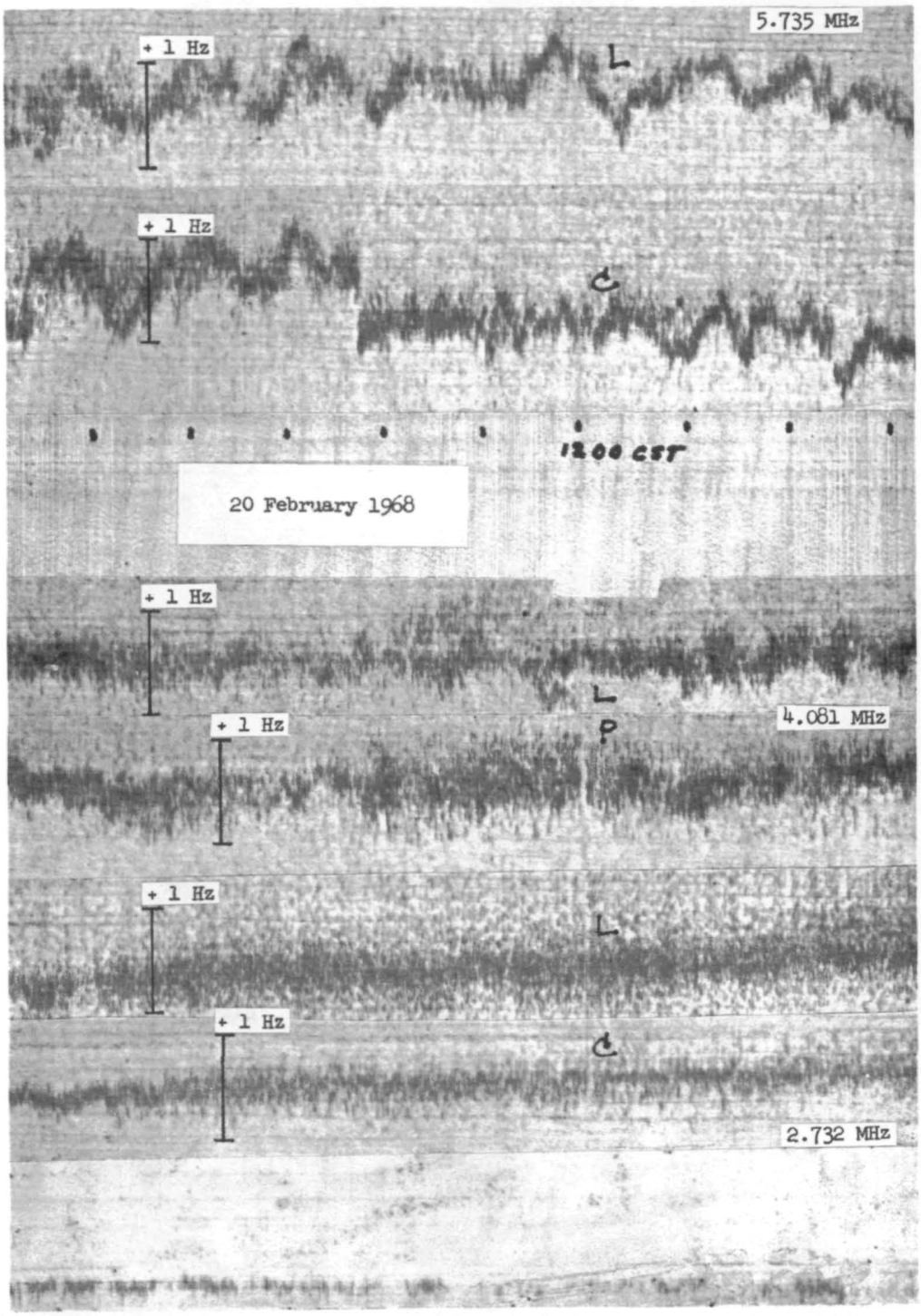


Figure 33 (a): Doppler data record,
20 February 1968: Huntsville, Alabama

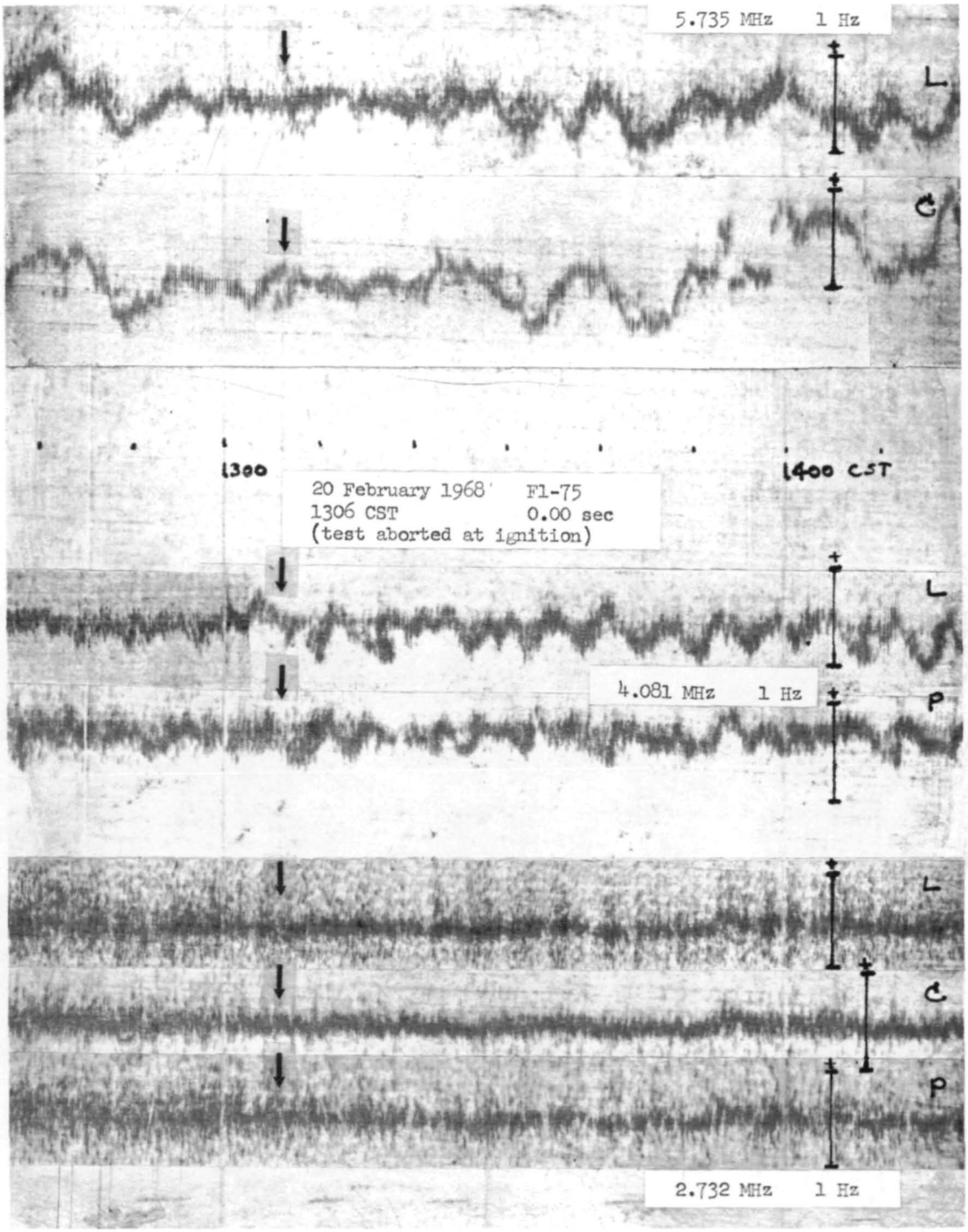


Figure 33 (b): Doppler data record,
20 February 1968: Huntsville, Alabama

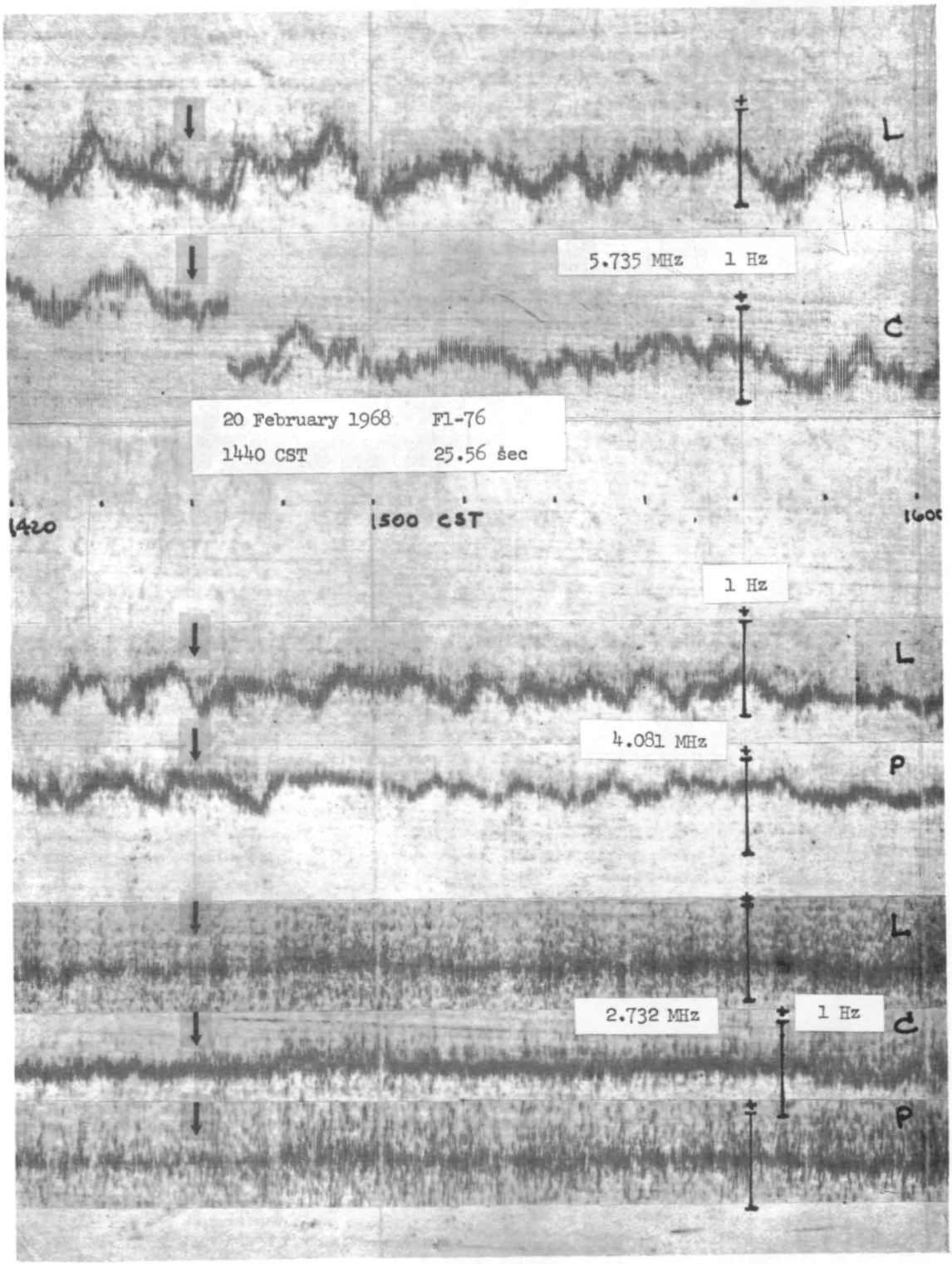


Figure 33 (c): Doppler data record,
20 February 1968: Huntsville, Alabama

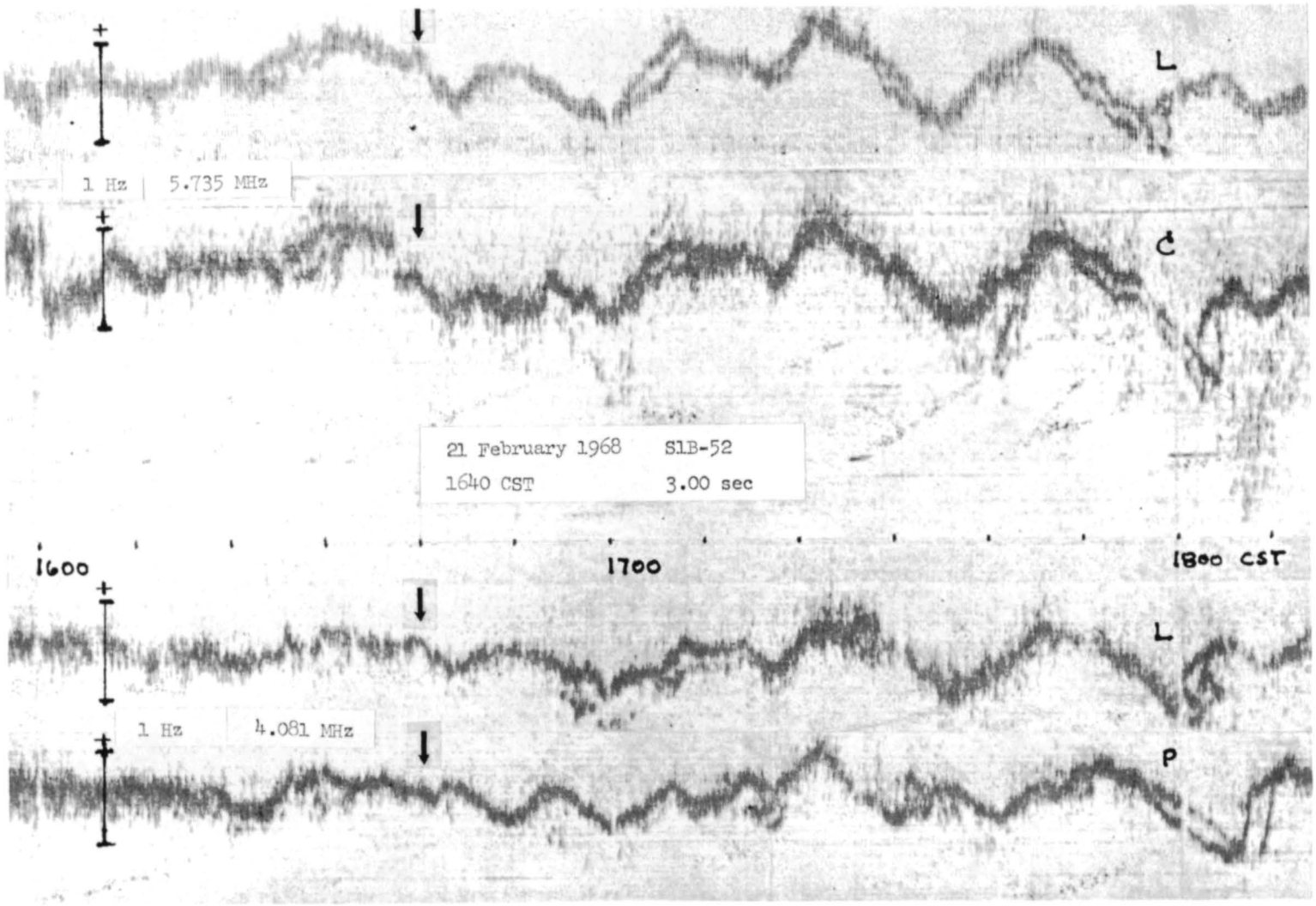


Figure 34 (a): Doppler data record, 21 February 1968: Huntsville, Alabama

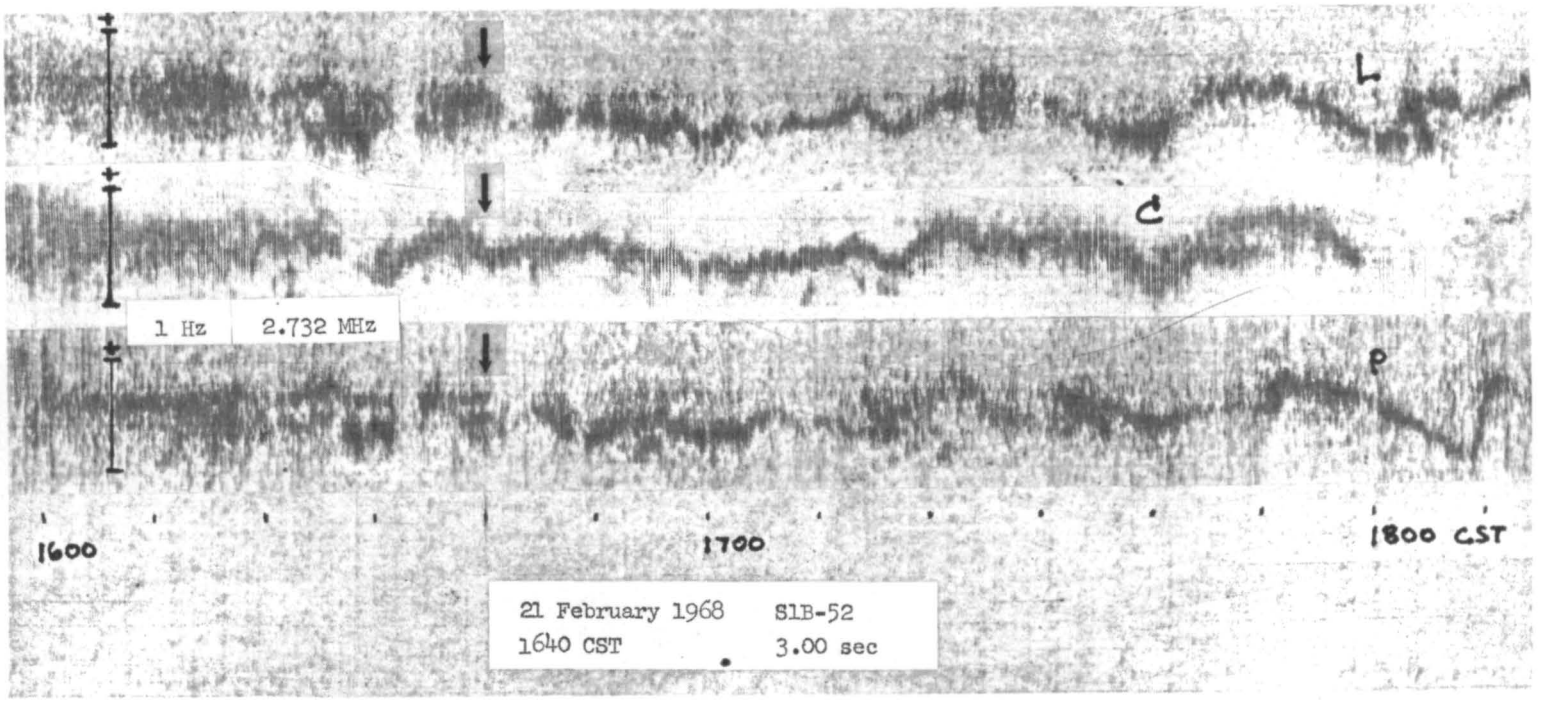


Figure 34 (b): Doppler data record, 21 February 1968: Huntsville, Alabama

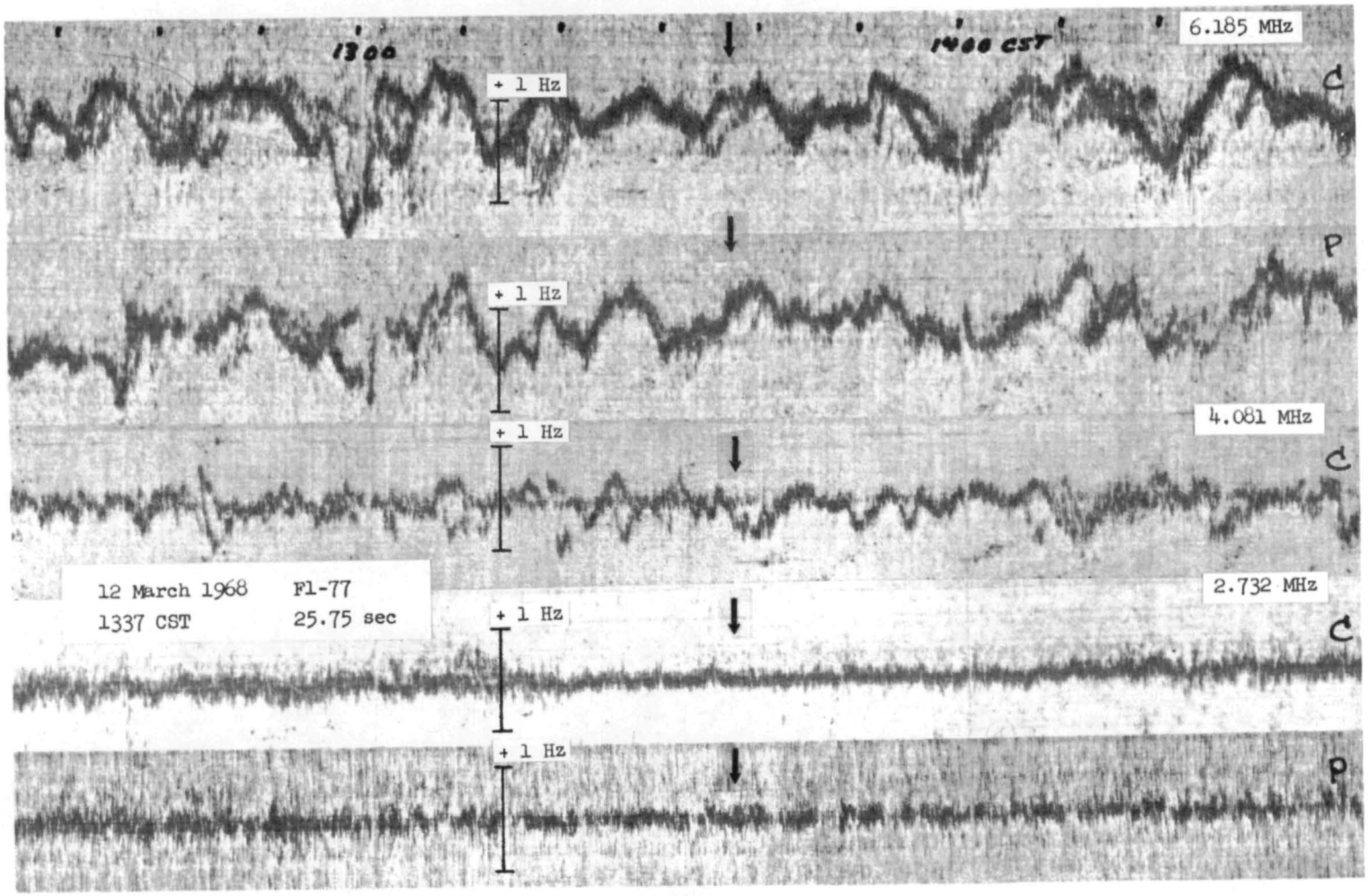


Figure 35: Doppler data record, 12 March 1968: Huntsville, Alabama

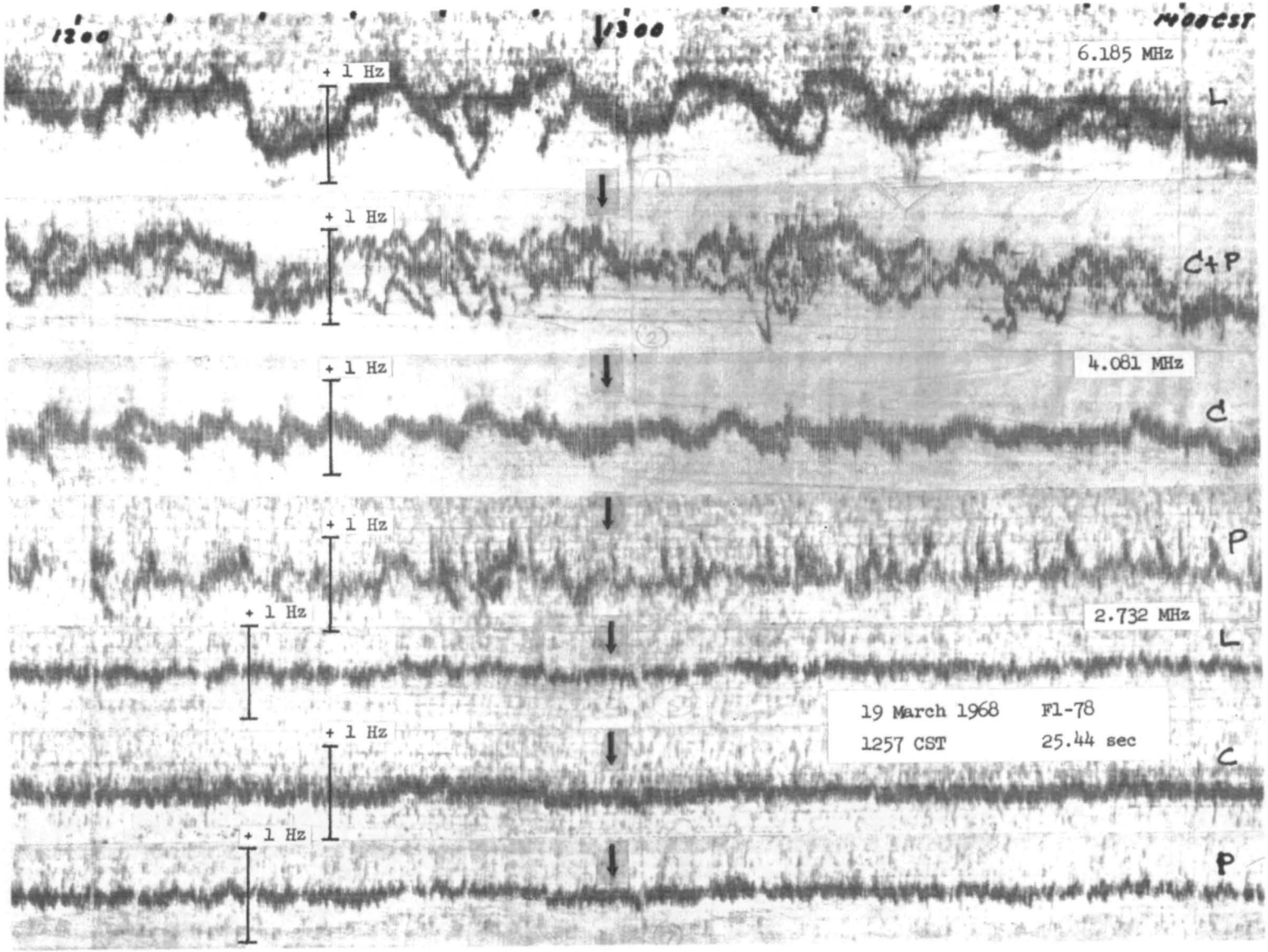


Figure 36: Doppler data record, 19 March 1968: Huntsville, Alabama

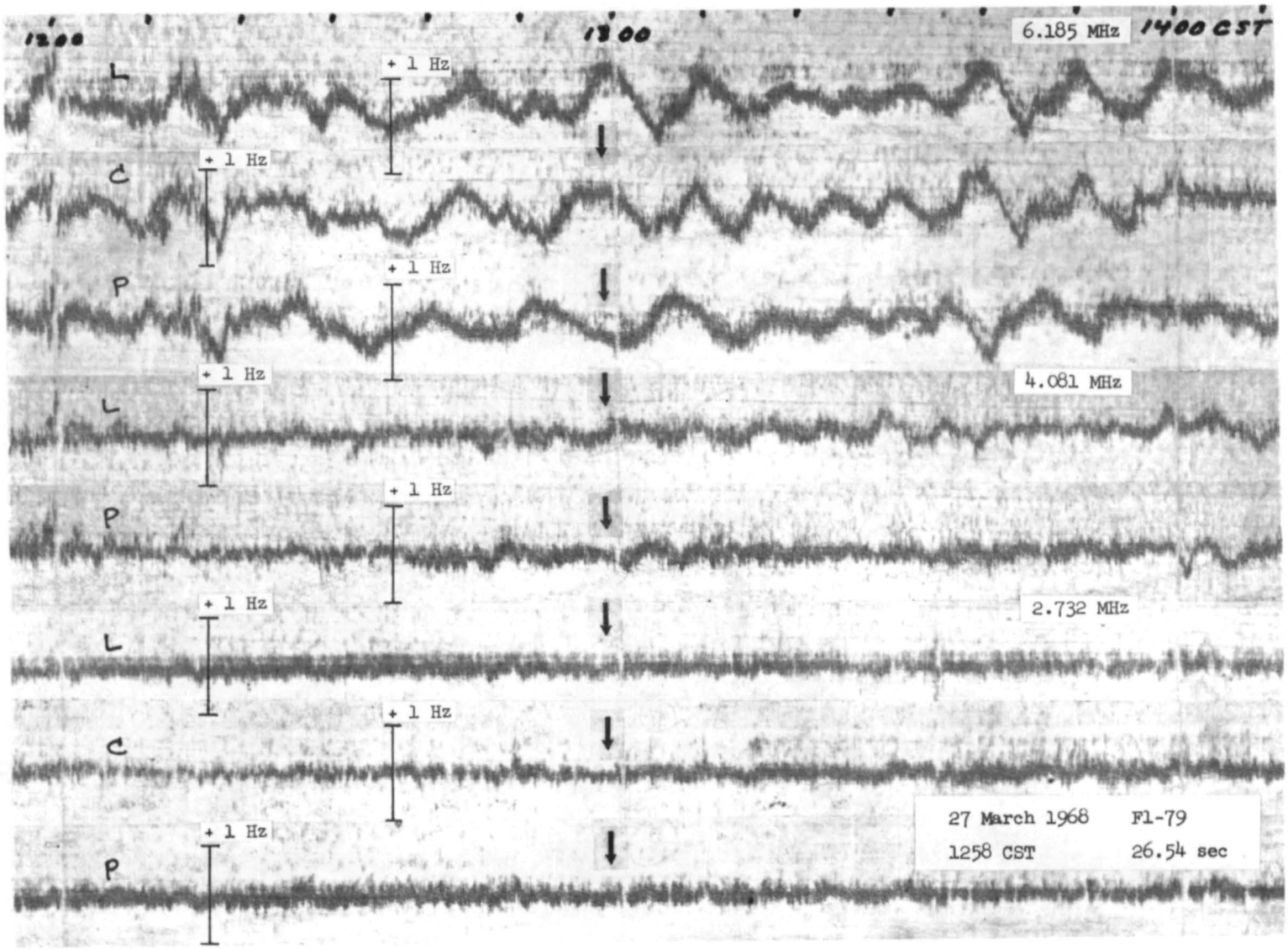


Figure 37: Doppler data record, 27 March 1968: Huntsville, Alabama

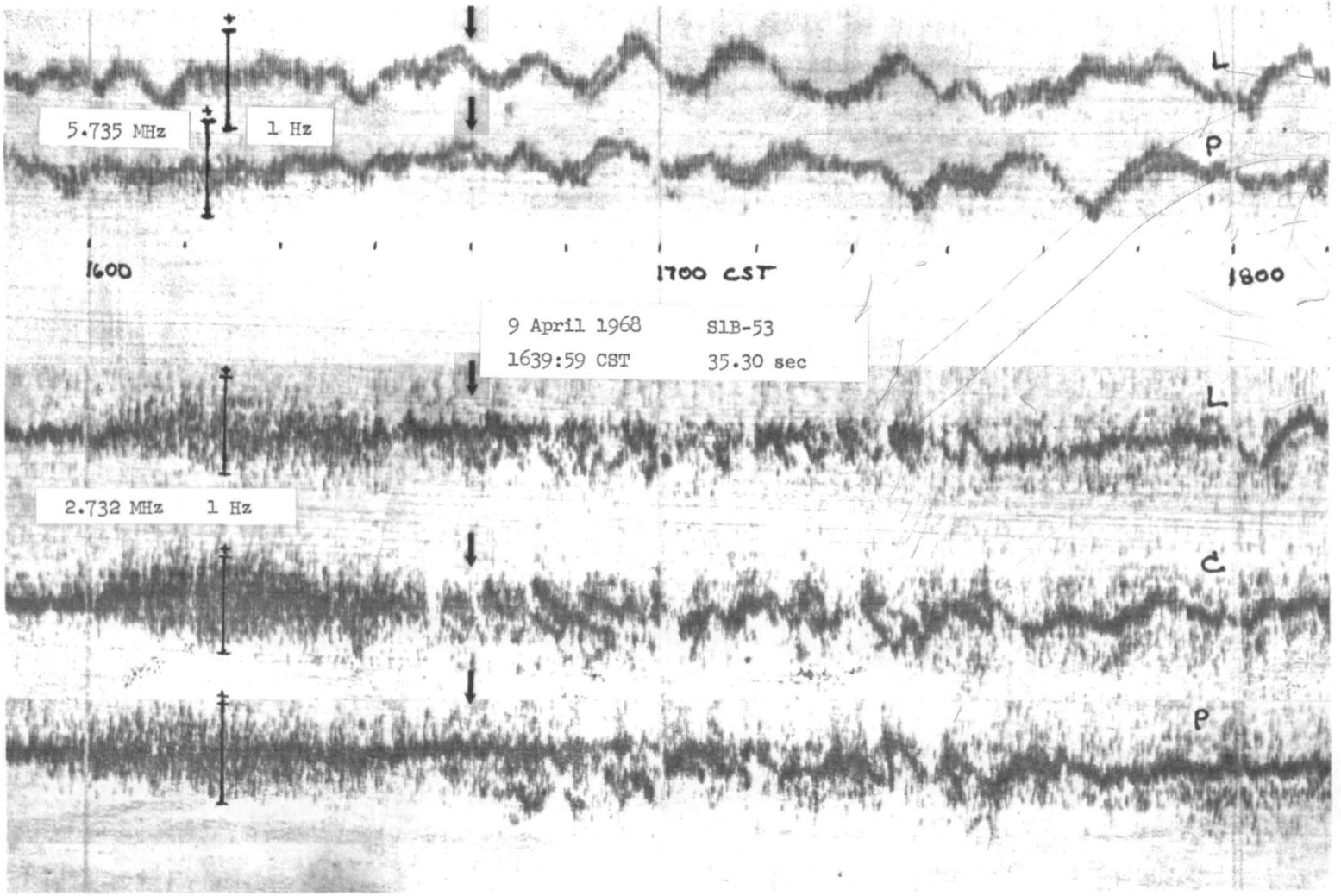


Figure 38 (a): Doppler data record, 9 April 1968: Huntsville, Alabama

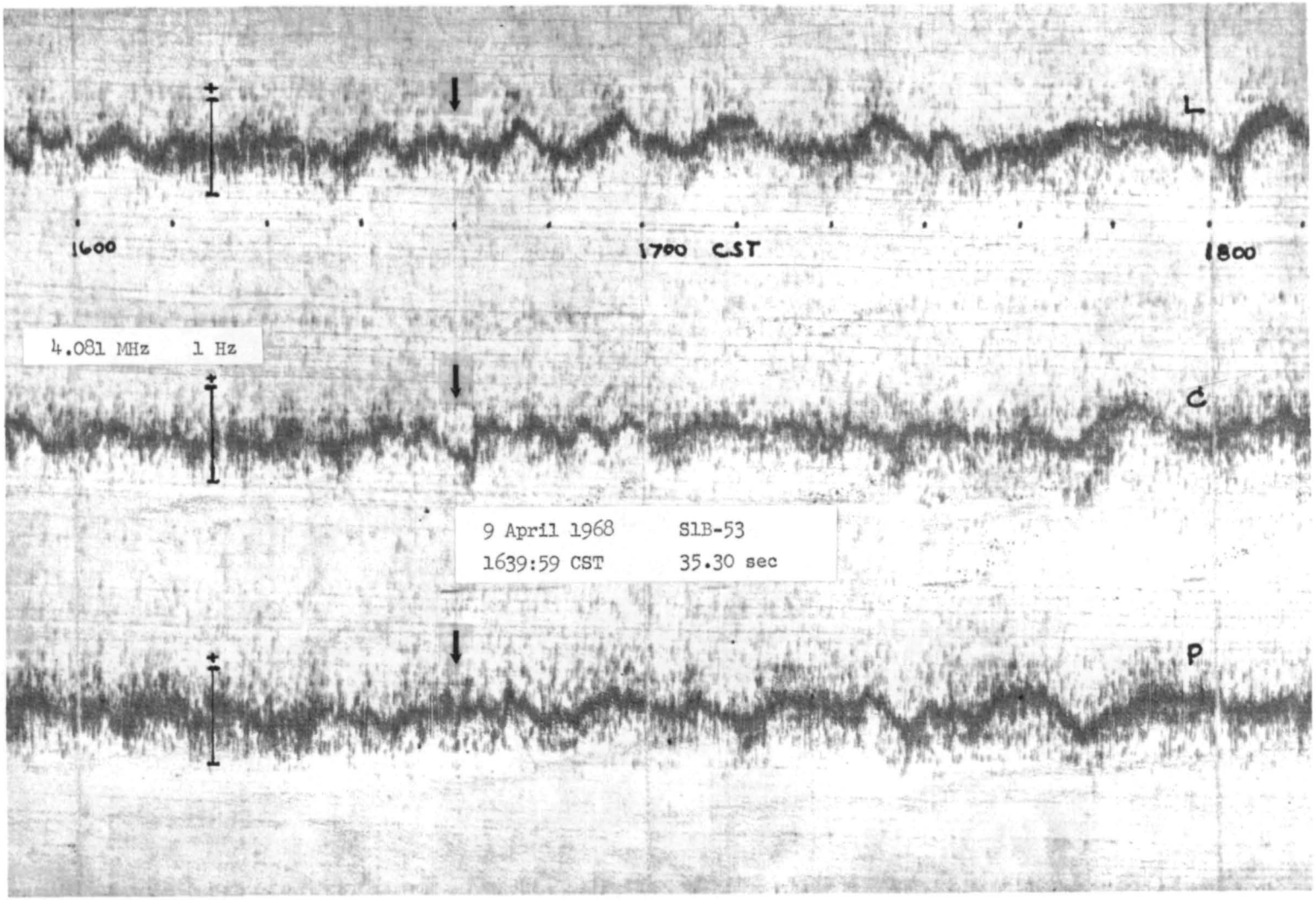


Figure 38 (b): Doppler data record, 9 April 1968: Huntsville, Alabama

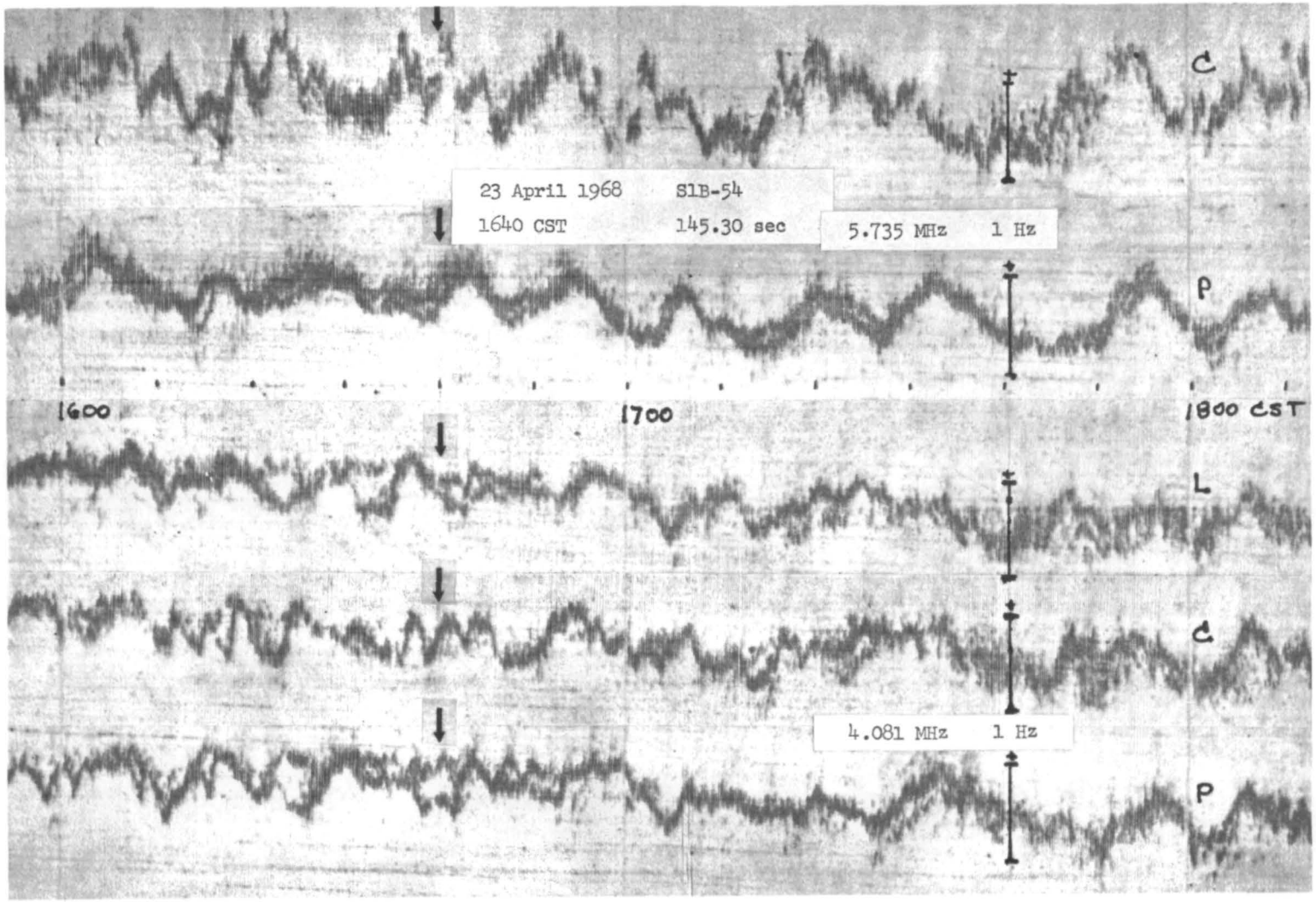


Figure 39 (a): Doppler data record, 23 April 1968: Huntsville, Alabama

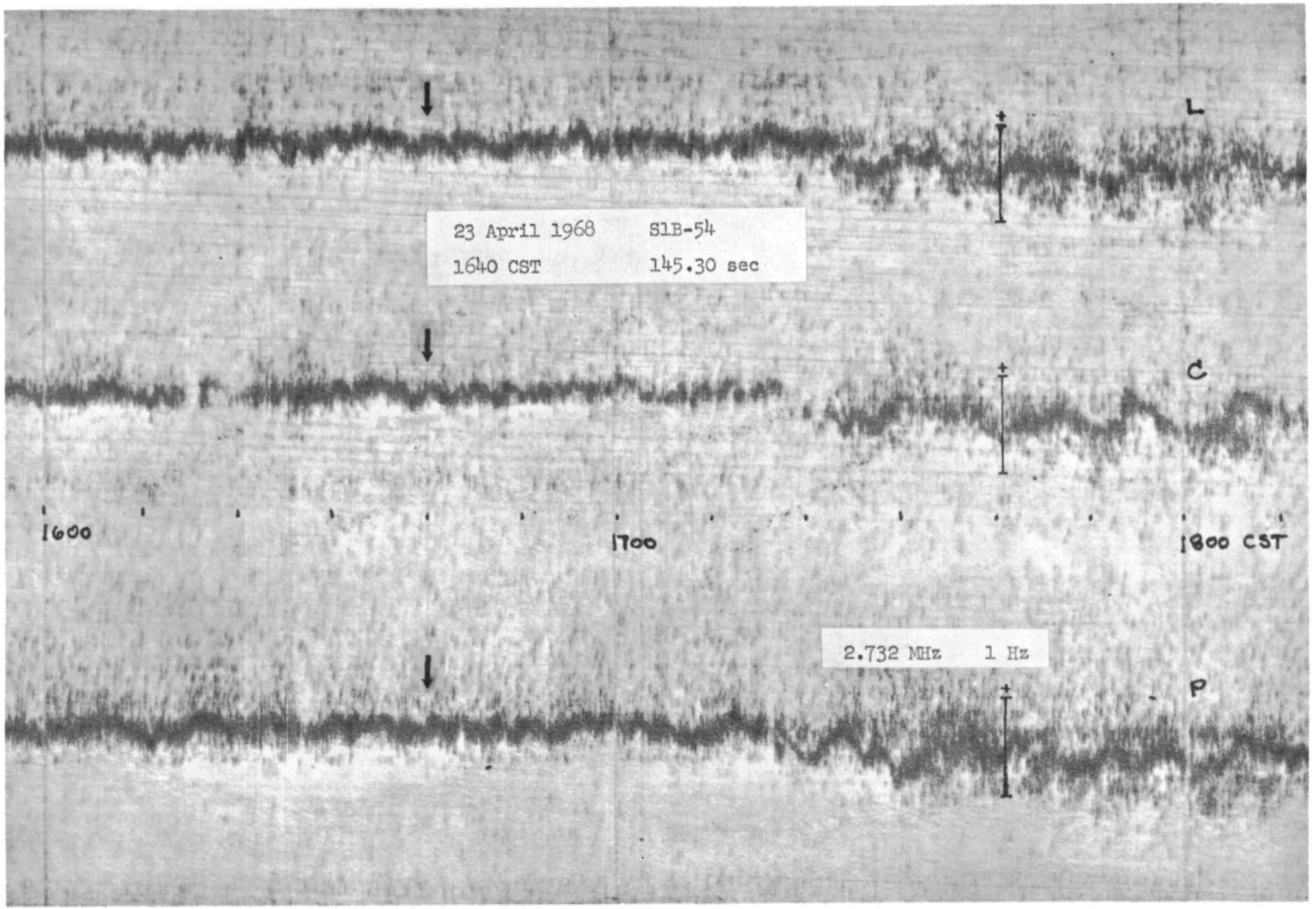


Figure 39 (b): Doppler data record, 23 April 1968: Huntsville, Alabama

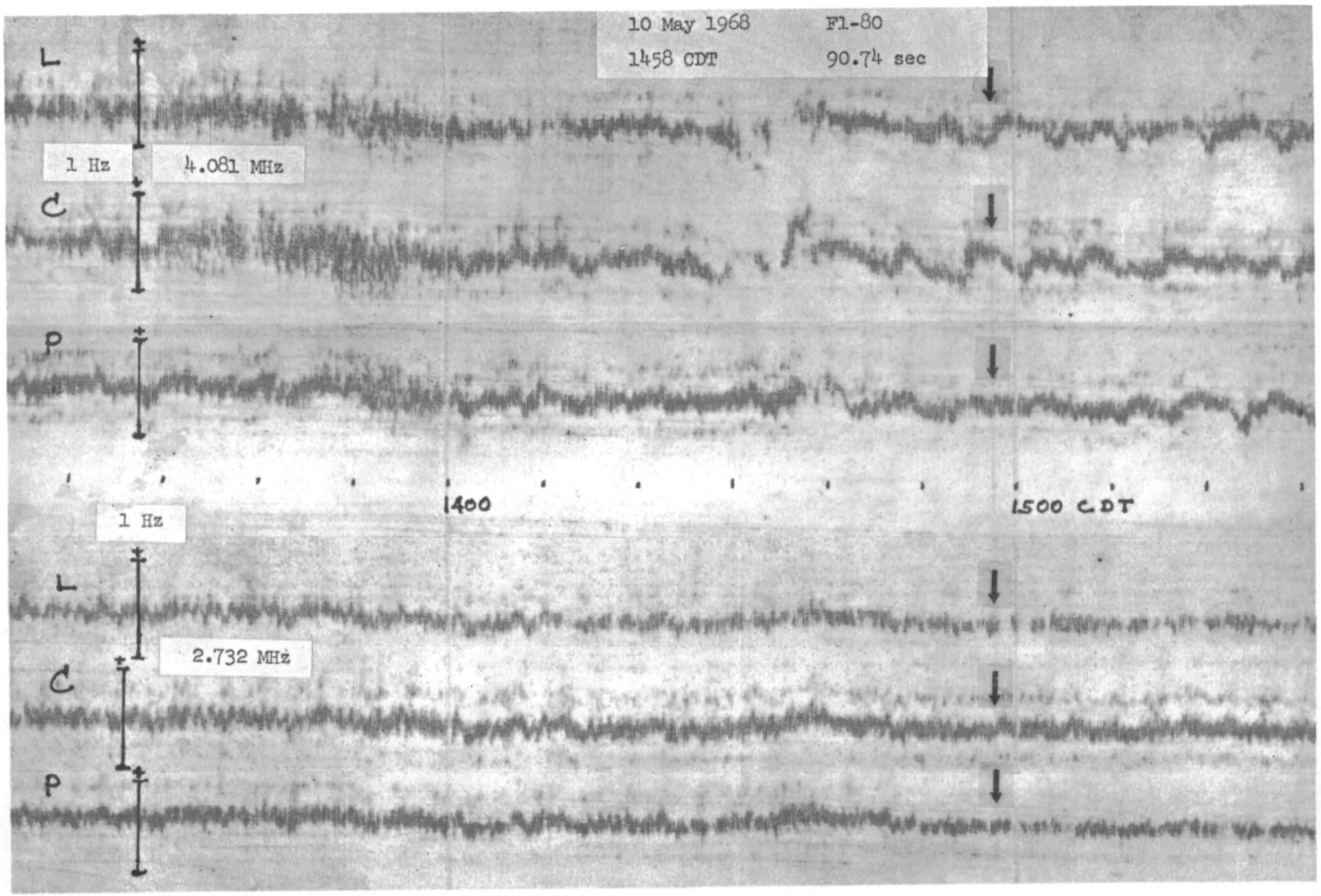


Figure 40 (a): Doppler data record, 10 May 1968: Huntsville, Alabama

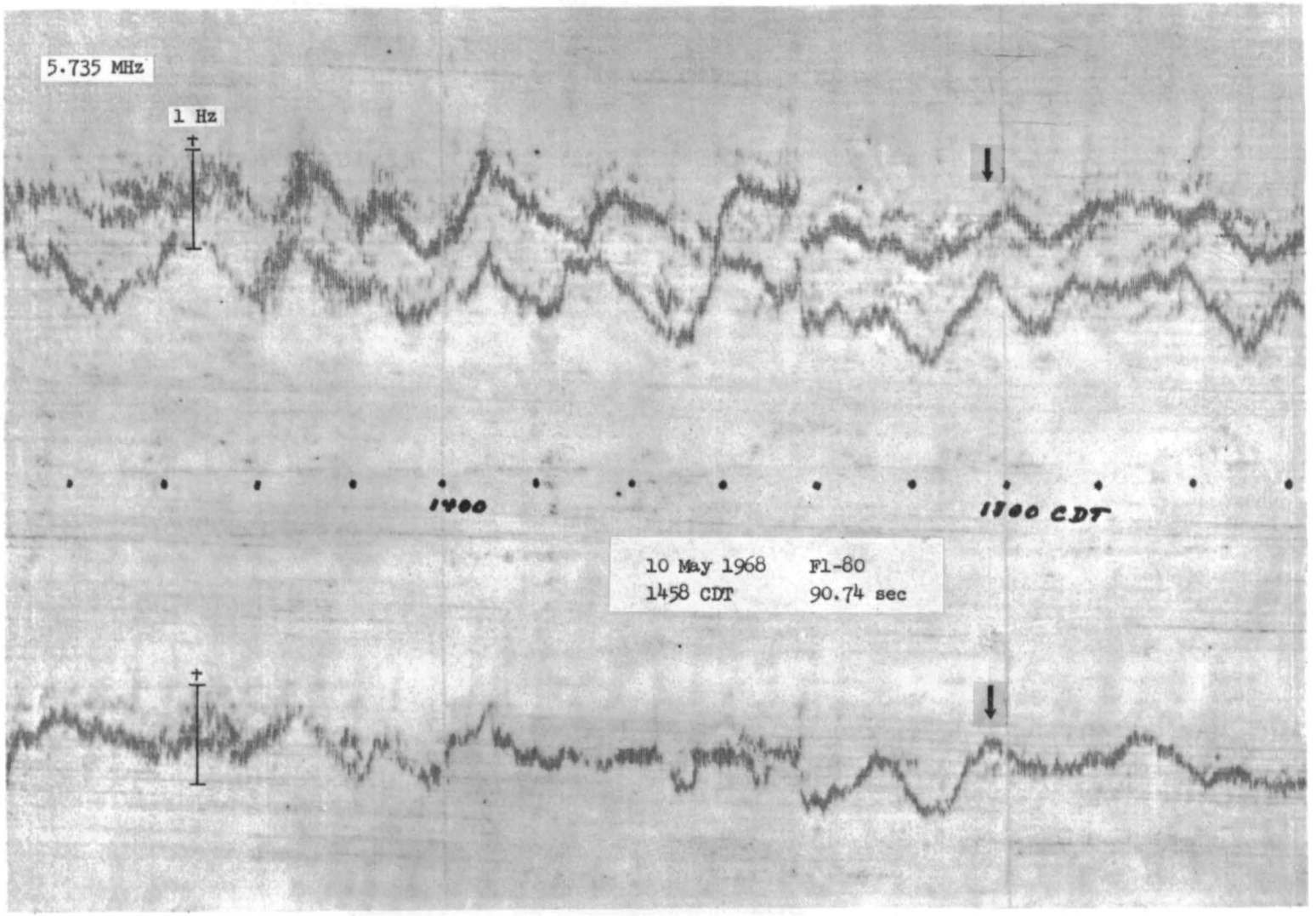


Figure 40 (b): Doppler data record, 10 May 1968: Huntsville, Alabama processed with low analyzer gain

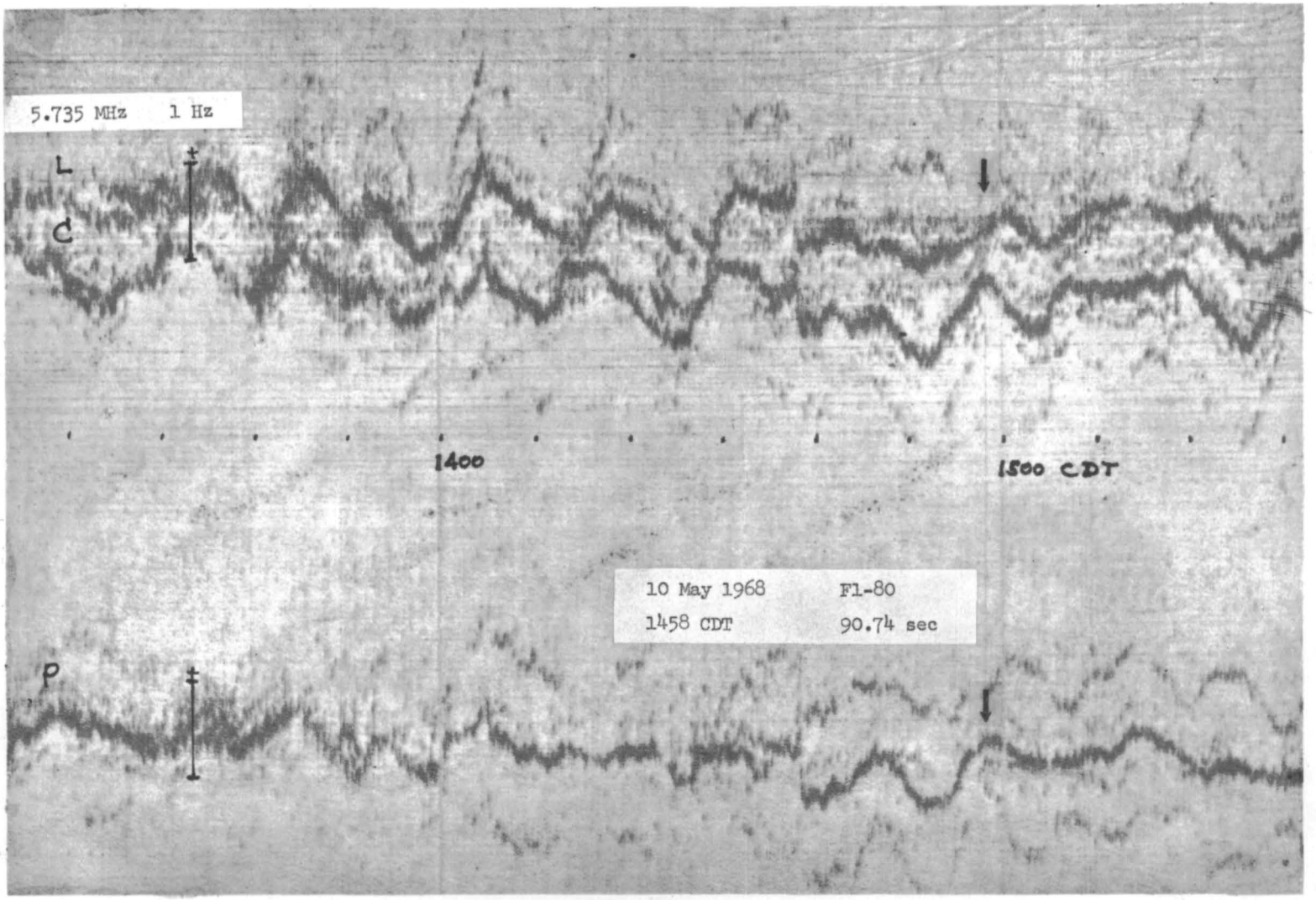


Figure 40 (c): Doppler data record, 10 May 1968: Huntsville, Alabama processed with intermediate analyzer gain

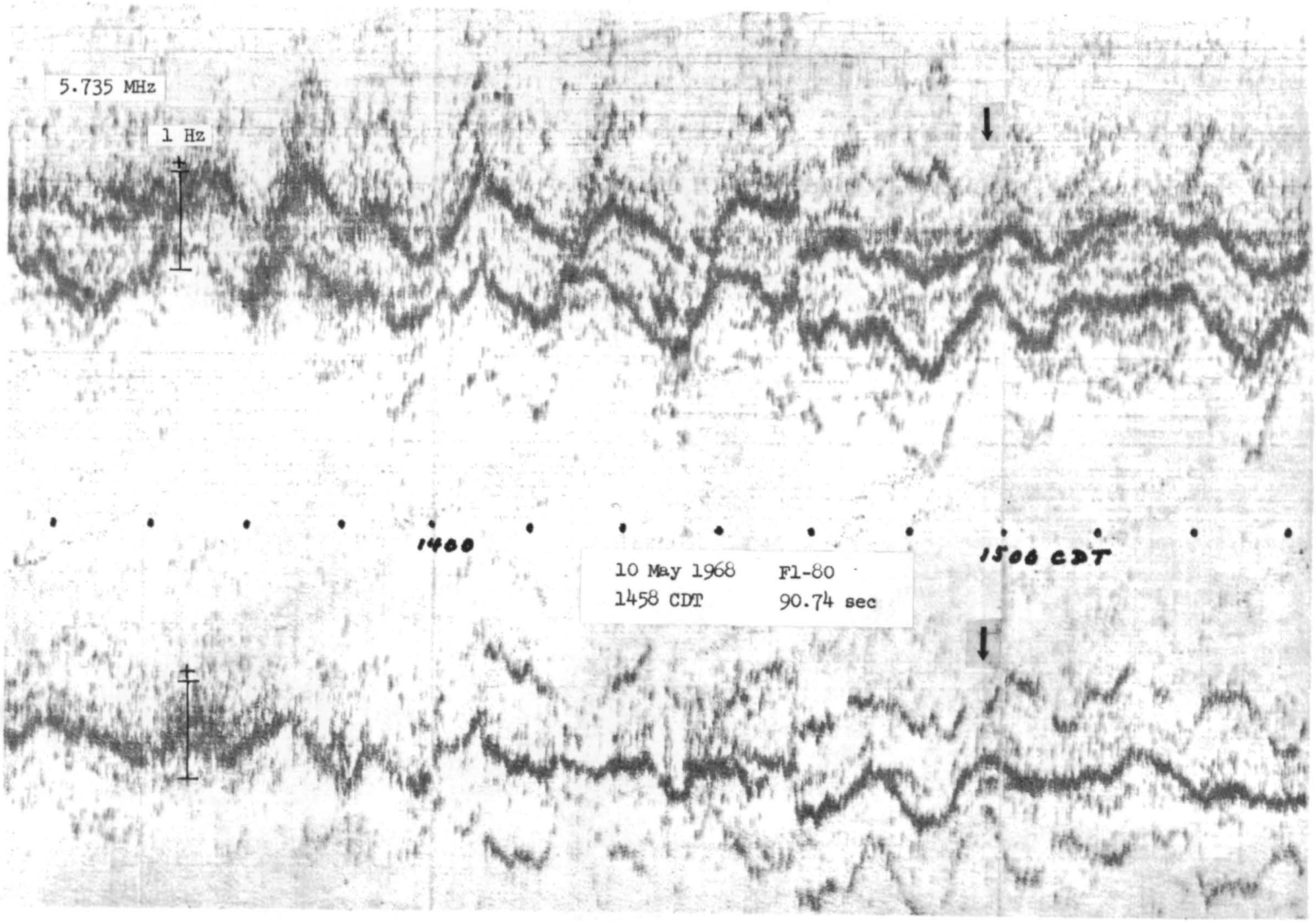


Figure 40 (d): Doppler data record, 10 May 1968: Huntsville, Alabama processed with high analyzer gain

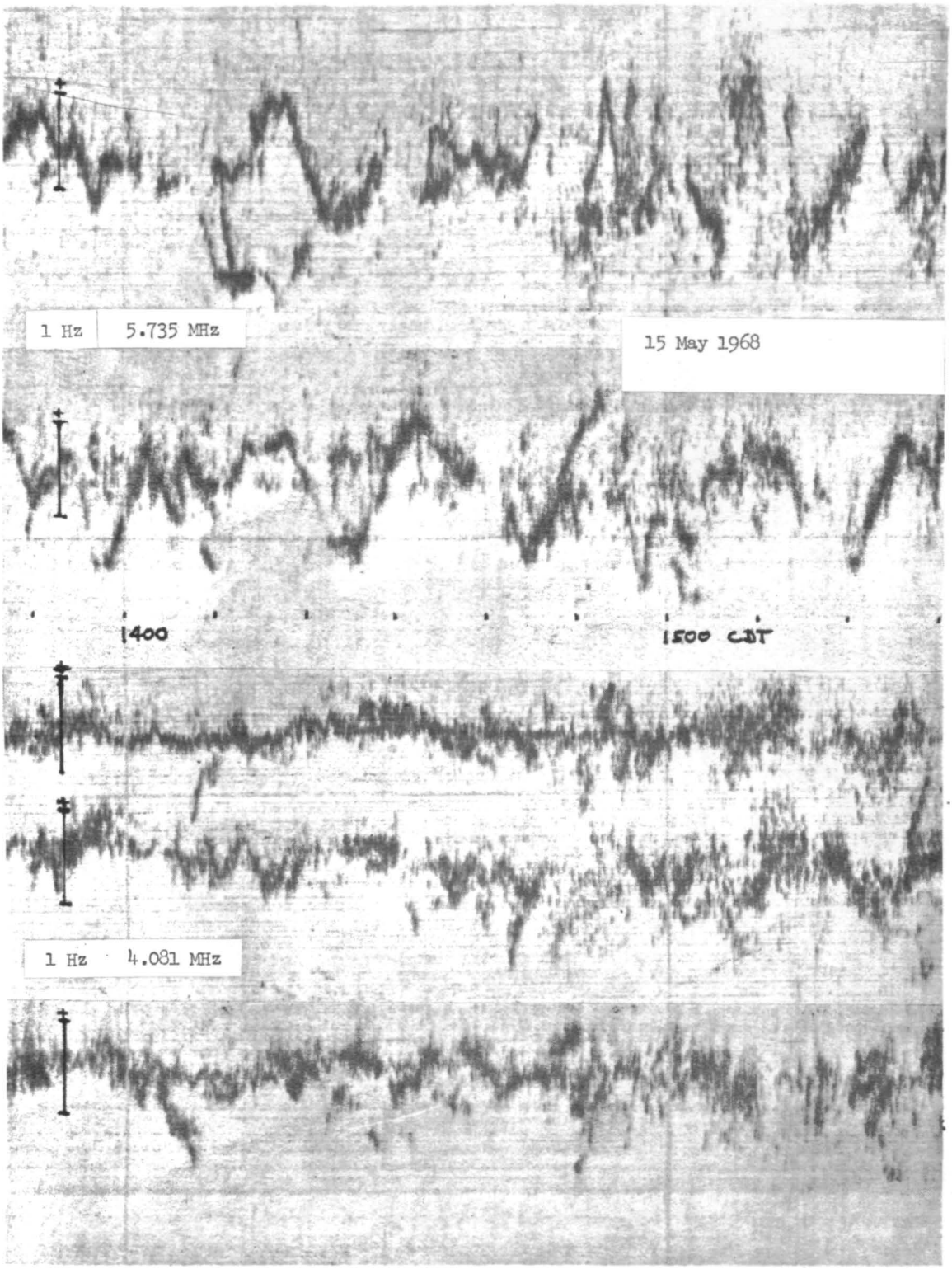


Figure 41 (a): Doppler data record,
15 May 1968: Huntsville, Alabama

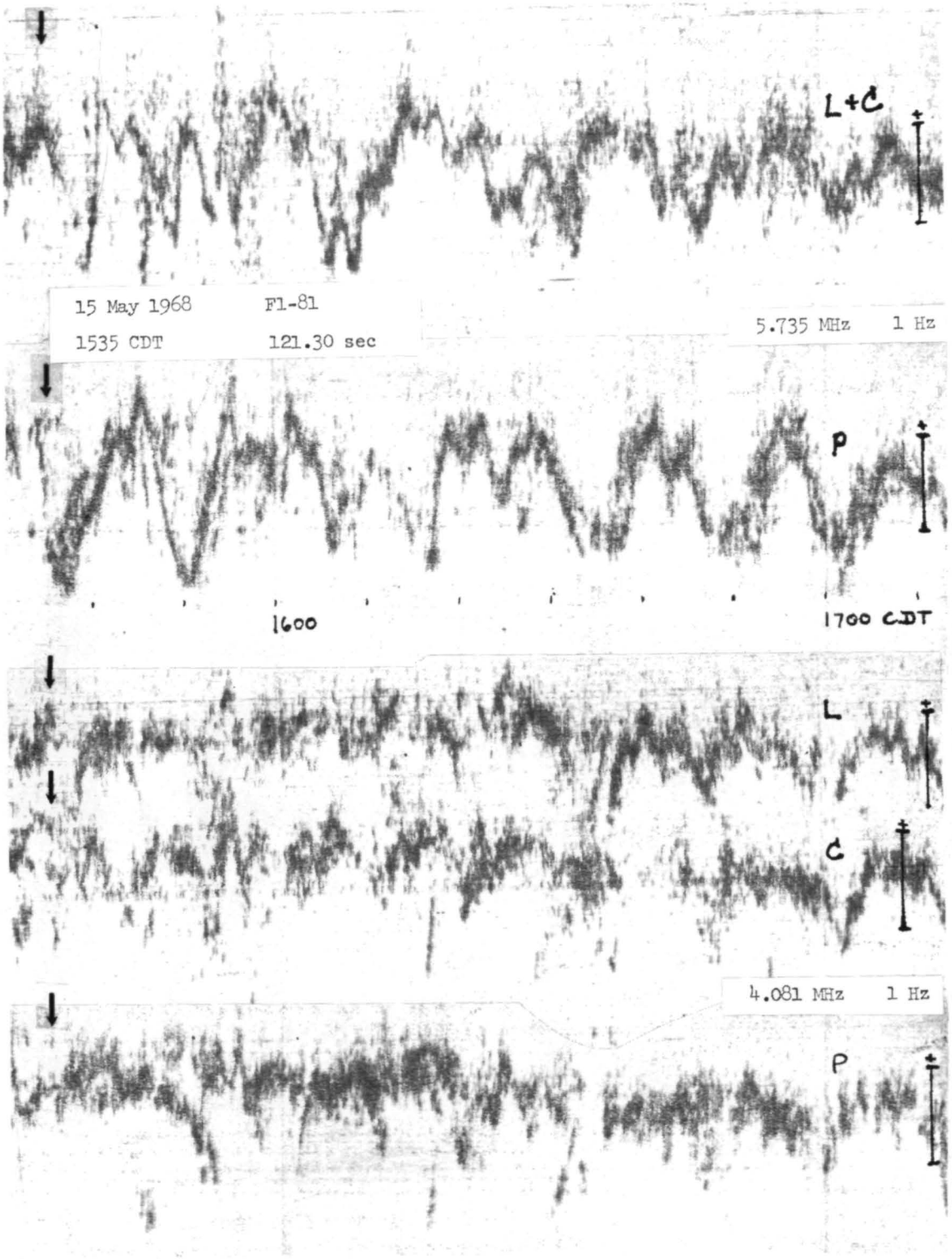


Figure 41 (b): Doppler data record,
15 May 1968: Huntsville, Alabama

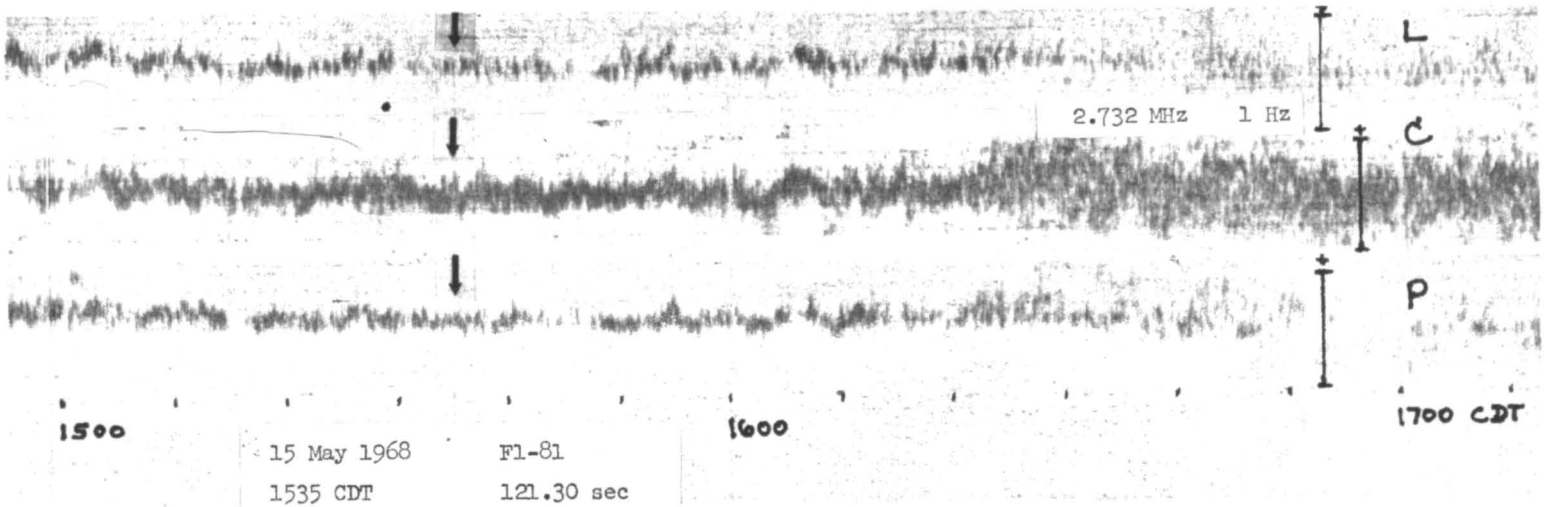
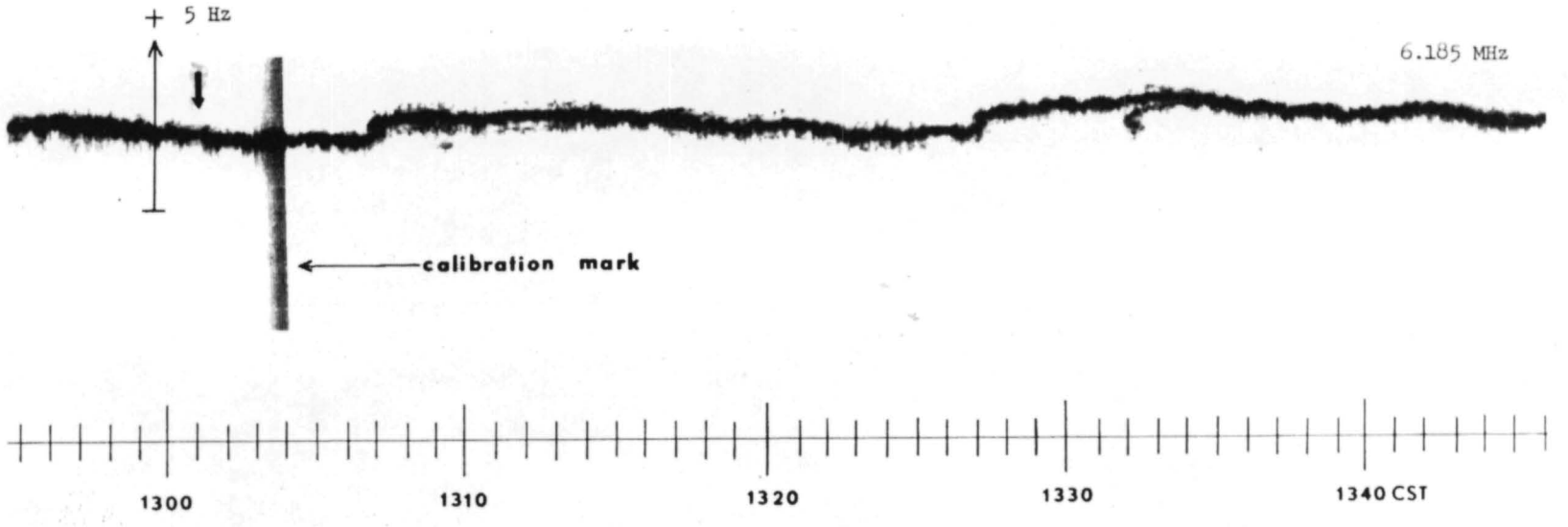


Figure 41 (c): Doppler data record, 15 May 1968: Huntsville, Alabama



20 April 1967 F1-61
1301 CST 40 sec

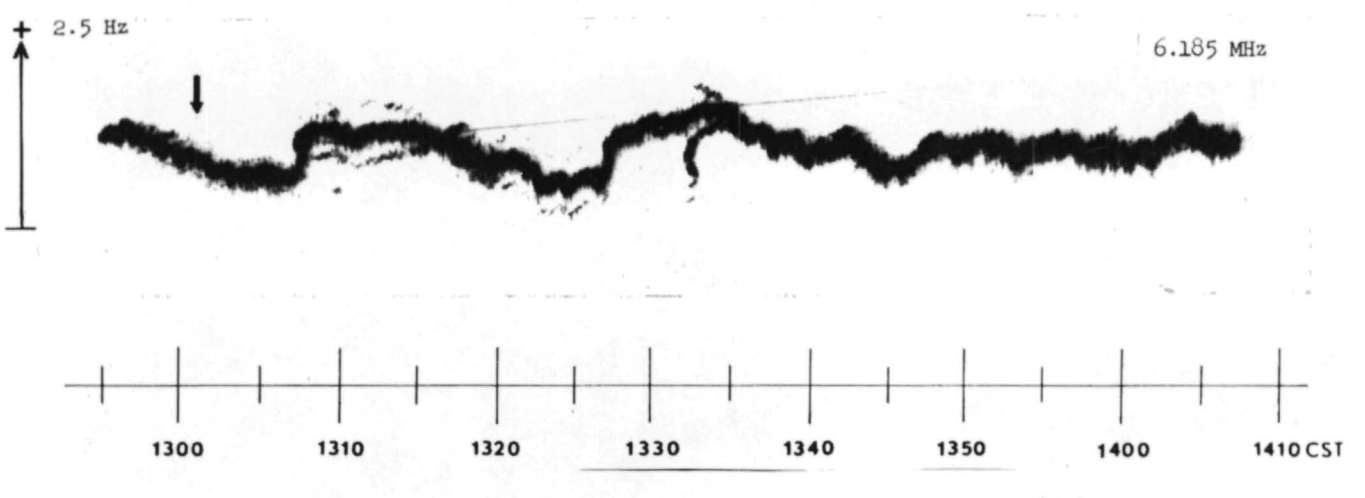


Figure 42: Doppler data record, 20 April 1967: Huntsville, Alabama

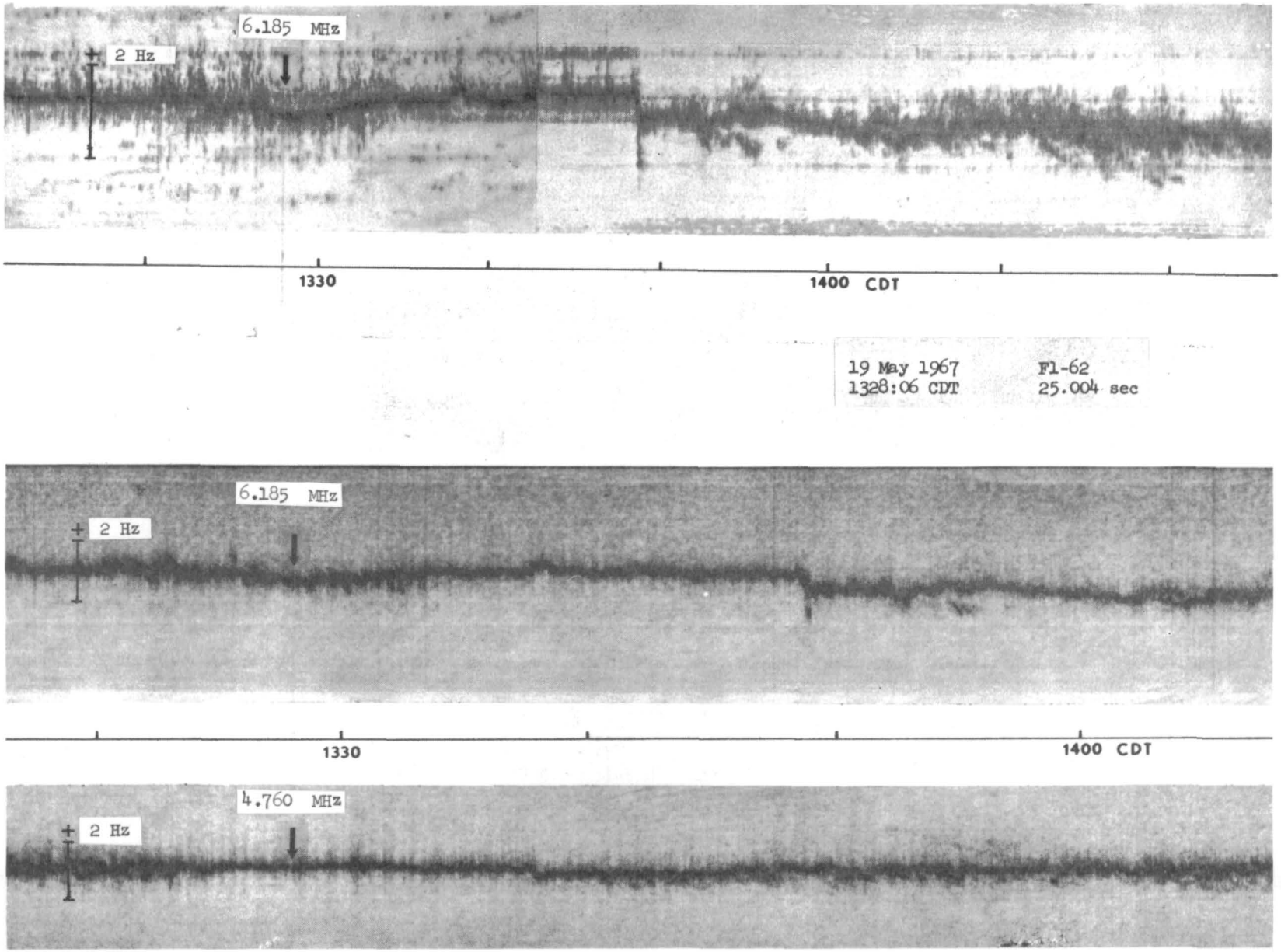


Figure 43: Doppler data record, 19 May 1967: Huntsville, Alabama

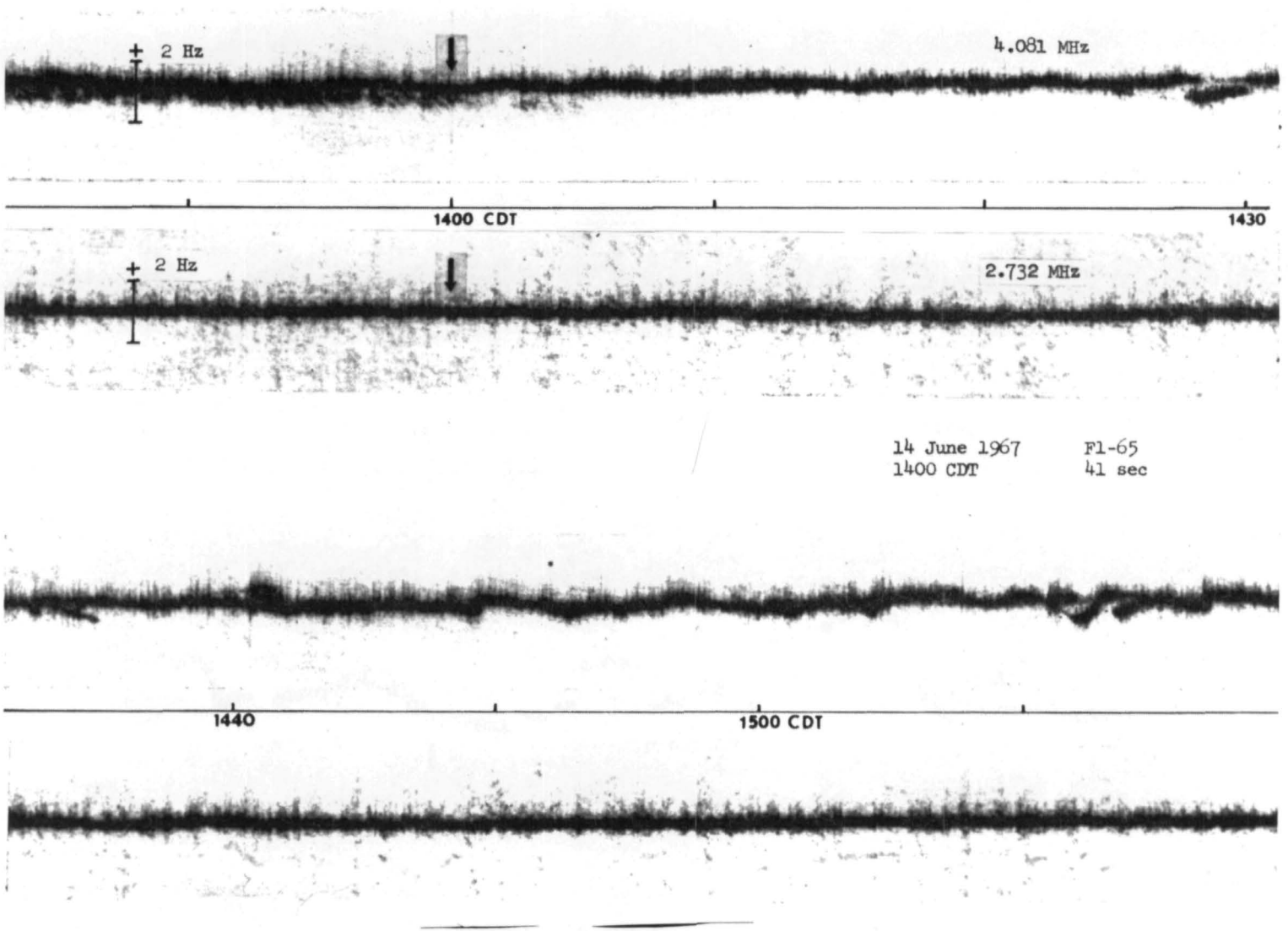


Figure 44: Doppler data record, 14 June 1967: Huntsville, Alabama

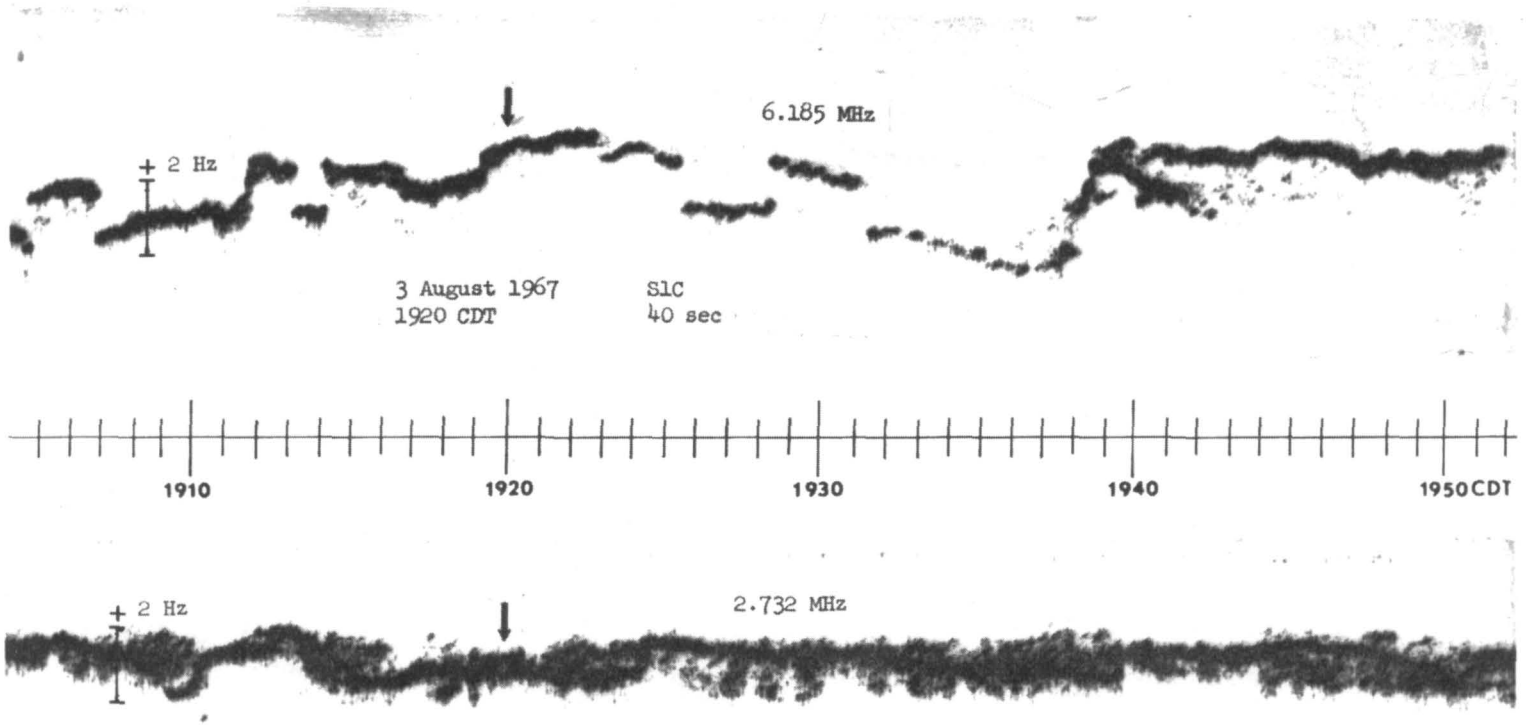


Figure 45: Doppler data record, 3 August 1967: Huntsville, Alabama

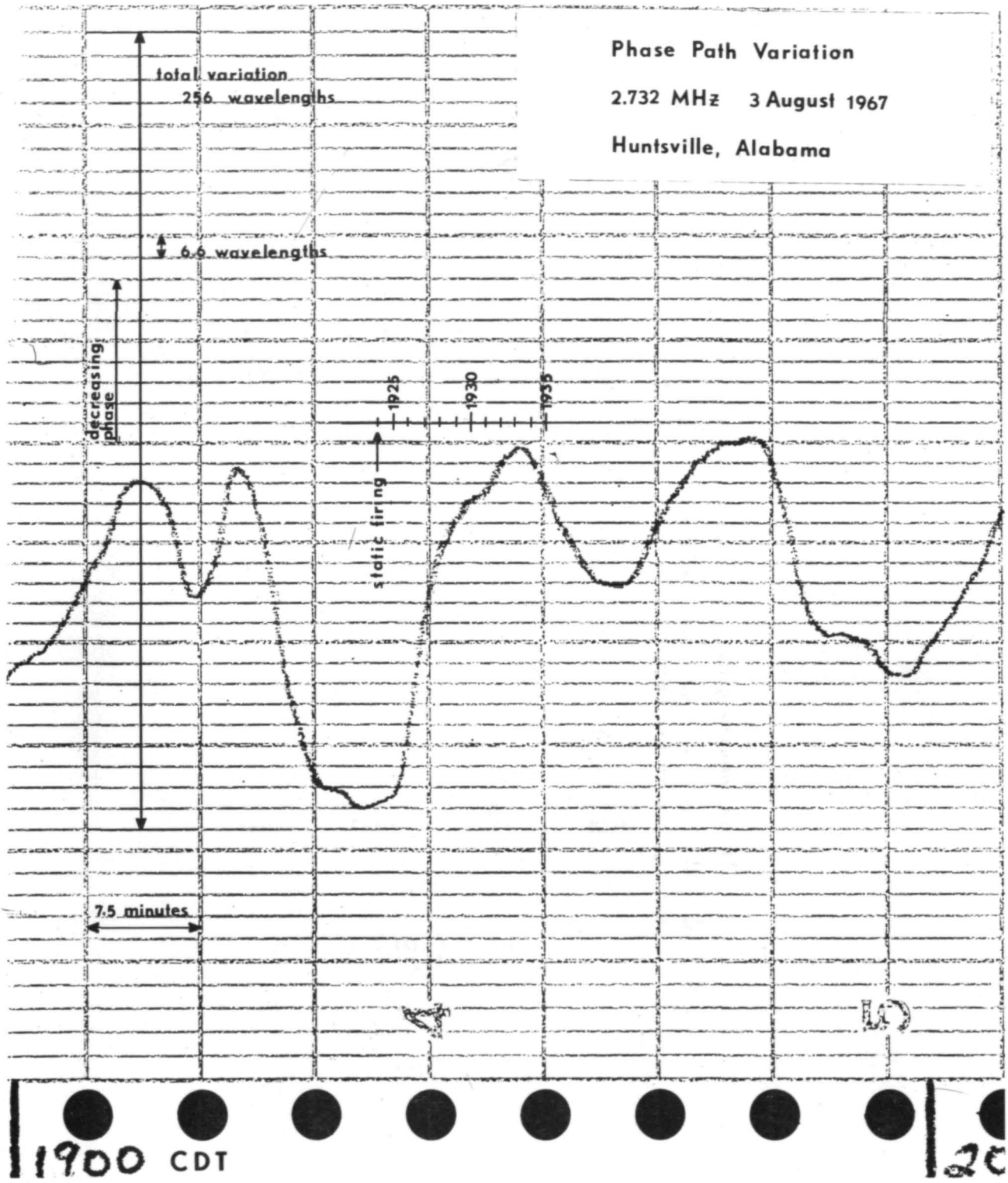


Figure 46: Phase-locked loop data record,
3 August 1967: Huntsville, Alabama

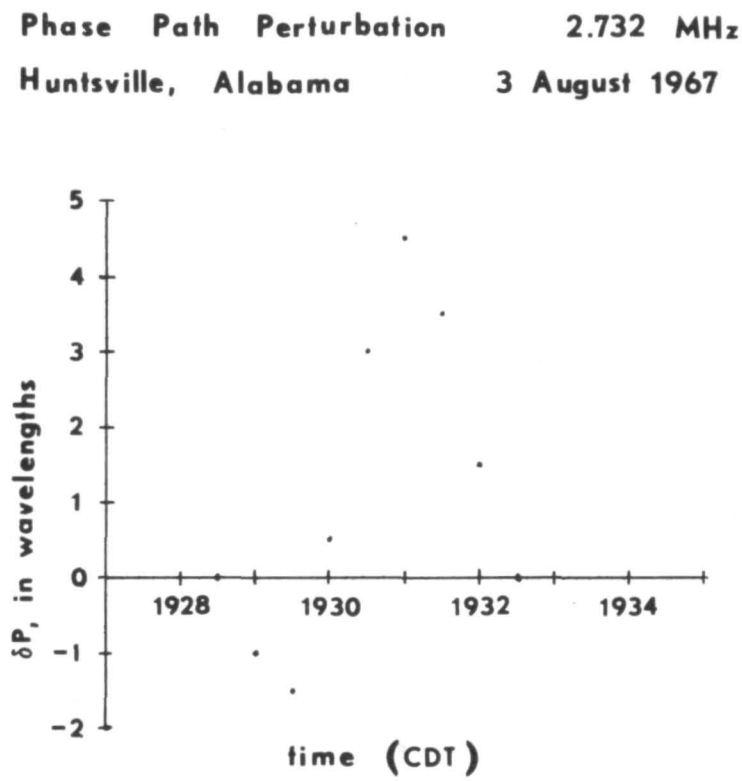


Figure 47

Phase path perturbation extracted from Figure 46

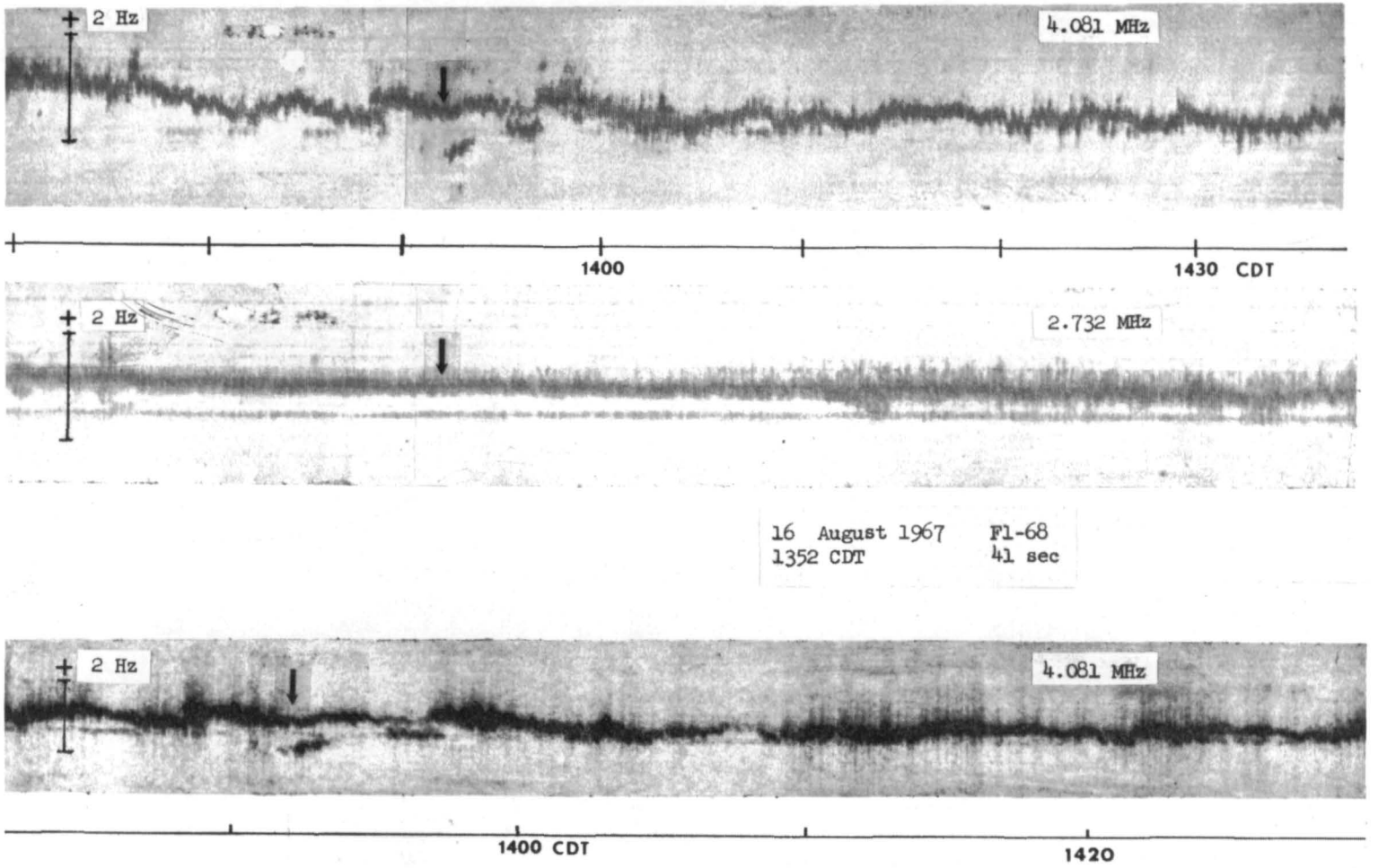


Figure 48: Doppler data record, 16 August 1967: Huntsville, Alabama

APPENDIX D

THE PROPAGATION OF ACOUSTIC-GRAVITY WAVES THROUGH THE MIDDLE ATMOSPHERE

(prepared by Charles Moo, Avco/SSD)

The propagation of acoustic-gravity waves to ionospheric heights from the troposphere is complicated by the presence of temperature and wind gradients in the intervening medium. These serve to extract energy from the incident wave, depending on wave frequency ω and the wind velocity and temperature profiles. The mean atmospheric density decreases with height, and the wave amplitude is inversely proportional to the square root of the mean density, so that if energy per unit volume is the same at two heights, the amplitude will be correspondingly larger at higher altitudes. Hines [21] has estimated that vertical energy fluxes of the order of 1 erg cm^{-2} sec^{-1} are required to obtain waves of the sort typically observed in the ionosphere. Gossard [22] and Pierce and Coroniti [15] computed fluxes leaving the troposphere of the order of 100 ergs cm^{-2} sec^{-1}, orders of magnitude above that required for observation at ionospheric heights if the waves were free of dissipation and reflection through the intervening atmosphere. Thus extensive and significant mechanisms for attenuation must obtain.

Viscosity and thermal conduction [23] dissipate atmospheric gravity waves at thermospheric heights, especially at the high frequency end of the spectrum. More important for troposphere-ionosphere coupling are the roles of thermal reflection and wind shear filtering. Hines [24] and Friedman [25] show that although thermal reflections at mesospheric heights reduce the energy coupled to the ionosphere, a major portion of the wave spectrum of acoustic-gravity waves would pass through to the lower ionosphere.

Of apparent major importance in restricting troposphere-ionosphere coupling is the possible occurrence of "critical layers", in which the wave frequency is Doppler shifted to zero, as measured in the reference frame moving with the background wind of the layer [26, 27, 28]. Under the conditions in which WKB approximations can be applied (i.e. for large Richardson number

$$R = \omega_b^2 / V^2$$

where ω_b is the Brunt frequency and V the horizontal wind speed) Bretherton showed that, for a travelling wave group with dominant frequency ω and horizontal wave number k_h, there is a critical level at which the Doppler shifted frequency

$$\Omega = \omega - k_h V$$

vanishes, and the wave in effect is not propagated above this level. Furthermore, the total wave energy of a wave packet is not conserved but is proportional to Ω. "Changes in the wave energy occur because an upward propagating internal wave is associated with a vertical transfer of horizontal momentum, and in a shear flow there is a continual transfer of energy between the mean flow and the wave, as the momentum is transferred up or down the mean velocity gradient (Eliassen and Palm [29])". [26]

APPENDIX E

ACOUSTIC RAY-TRACING PROGRAM

(prepared by Sheldon Weinstein, Avco/SSD)

A three-dimensional acoustic ray-tracing computer program, originally developed by Pierce [20] at Avco/SSD, has been modified slightly and rewritten in a format suitable for general purpose usage. The principal change incorporated into Pierce's skeleton code was the replacement of his rather simple numerical integration method by a standard Adams-Moulton integration routine with error checking and variable step size. This was required in order to reduce the errors accumulated when integrating along a raypath with steps of fixed incremental length.

The following is a brief, user-oriented description in outline form of the essence of the program, the required input data, and its outputs for operation on the Avco IBM 360/75 computer, utilizing the SC-4020 digital microfilm plotter. Details of the mathematical approach and its computer implementation are found in Pierce's report.

1. Purpose

Integration of the three-dimensional atmospheric acoustics ray-tracing equations in a temperature and wind stratified atmosphere, winds being considered two-dimensionally within each stratum.

2. Equations

$$\frac{dt}{dz} = \frac{\frac{\Omega}{c^2}}{k_z} \tag{1}$$

$$\frac{dx}{dz} = \frac{k_x + v_x \frac{\Omega}{c^2}}{k_z} \tag{2}$$

$$\frac{dy}{dz} = k_y + v_y \frac{\Omega}{c^2} \tag{3}$$

$$\Omega = 1 - k_x v_x - k_y v_y \tag{4}$$

$$k_z^2 = \frac{\Omega^2}{c^2} - k_x^2 - k_y^2 \tag{5}$$

$$k_x = \frac{\sin\theta \cos\phi}{c} \tag{6}$$

$$k_y = \frac{\sin\theta \sin\phi}{c} \tag{7}$$

$$c = \sqrt{\frac{1.4 \times 8.3144 \times 10^{-3}}{29} \times (T + 273)} \tag{8}$$

where (see Figure 49)

- t dependent variable time (sec)
- x, y } dependent variables - horizontal distances (km)
- z independent variable height (km)
- v_x, v_y } horizontal wind velocity components (km/sec)
- T air temperature (°C)
- c sound velocity (km/sec)
- θ elevation angle, measured down from the vertical
- ϕ azimuth angle, measured clockwise from north

3. Numerical Integration Method

The solution of the set of three differential equations, (1), (2), and (3), is performed by Adams-Moulton integration. The method is implemented with a standard computer library predictor-corrector integration routine, using a four-point Runge-Kutta corrector scheme. Integration steps (in height) are of variable length, selected by the predictor-corrector procedure so as to bring the difference between the predicted and corrected values of t, x, and y to within error tolerance limits specified by the program user.

The advantage of this approach is maintenance of the required accuracy of the dependent variables, by checking the differences between the extrapolated and interpolated results for each incremental step and changing the step size of the independent variable to control accuracy while optimizing program speed. Operationally acceptable error limits have been chosen by requiring the ground-to-reflection and reflection-to-ground halves of the height vs. time raypaths to be symmetirc about their reflection points, a condition which can be invoked from the physics of the process. The integration error tolerance limits thusly

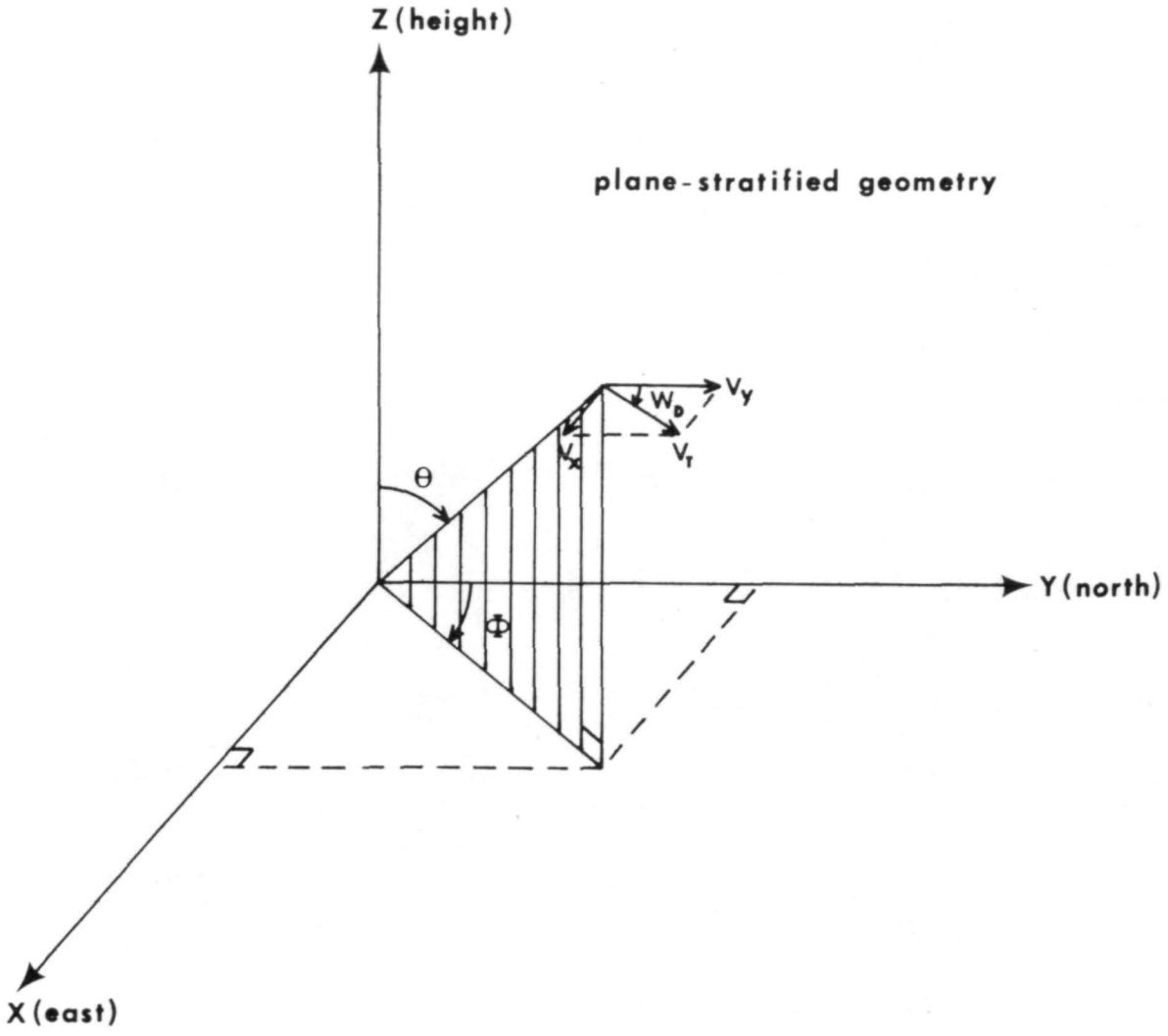


Figure 49: Ray-tracing program geometry

derived are currently preset in the program in UPBND and DNBND as follows:

UPBND = 10^{-2}, 1, 1 (upper bound on errors in t, x, y)

DNBND = 10^{-4}, 10^{-2}, 10^{-2} (lower bound on errors in t, x, y)

If the errors in any of the variables exceed UPBND, the step size is decreased to improve accuracy. If the predicted and corrected values of all the functions differ by less than DNBND, the step size is increased to reduce computer time.

4. Input Data

4.1 Atmospheric Profile

4.1.1 Title Card

Any information in columns 1 - 72.

4.1.2 Profile Data Cards (300 maximum)

Column	Contents	Remarks
2-11	Height (km)	Real - Decimal Point/F10.0
12-21	X component of wind velocity (km/sec)	〃
22-31	Y 〃	〃
32-41	Temperature (°C)	〃

4.1.3 End of Profile Data

Column	Contents	Remarks
1	9	This card signifies the end of the Profile Data.

4.1.4 Parameter Cards

The following parameters are input via Variable Field Input. The parameter name followed by its value is punched in columns 2 - 72. A blank is the delimiter between parameters and between parameters and their values.

Parameter	Description	Preset Value*
ITHETAI	Initial value of Elevation Angle (Degrees)	1
ITHETAF	Final 〃	89
ITHETAST	Step 〃	1
PHI	Azimuth angle (Degrees)	45
ZS	Initial Height (km)	0
TS	Initial Time (sec)	100
XS }	Initial horizontal coordinates (km)	0
YS }	(km)	0
TMARK	Increment for Time Tic marks (sec) on summary graphs	100

* Note: If parameter is not input, this value is used.

4.1.5 End of Parameters

Column	Contents	Remarks
1	Any integer	This card signifies the end of parameter input.

4.1.6 End Card*

Column	Contents	Remarks
1-3	END	This card signifies the end of all data.

* Note: Additional cases consisting of items 4.1.4 and 4.1.5 may be placed before the End Card.

5. Output

5.1 Atmospheric Profile Table
5.2 Input Parameter Table
5.3 Ray Table for each specified elevation angle
5.4 Plots of Atmospheric Profile
5.5 Plots of Ray Variables
5.6 Summary Plots of Ray Variables

Figures 50-55 show program-produced plots of sample input temperature and wind data, as well as vertical profiles of orthogonal wind components and sound speed derived therefrom. The particular temperature and wind profiles represented here were synthesized from the following sources, using free-hand extrapolations where required.

WINDS

Height Regime	Data Source
0-16.3 km	MSFC balloon release [30], 1901 UT, 20 April 1967
25-70	White Sands MRN [31] mean wind direction and vector speed values for April
85-170	Average midlatitude ionospheric meridional and zonal wind patterns, after Rosenberg [32]
above 170	Mid-latitude upper atmospheric wind regimes, after Smith and Weidner [33]

TEMPERATURE

Height Regime	Data Source
0-16.3 km	MSFC balloon release [30], 1901 UT, 20 April 1967
25-120	Standard atmosphere [34], mid-latitude spring/fall
120-300	Model atmosphere [34], spring/fall, exospheric temperature of 800°K.

Figures 56-61 show computer drawn summary output plots of raypaths traced at an azimuth of 45°, using the above data, through a series of elevation angle between 1° and 81°, in 10° steps. (The small numbers at the ends of the ray trajectories give the launching elevation angle for the particular raypath.)

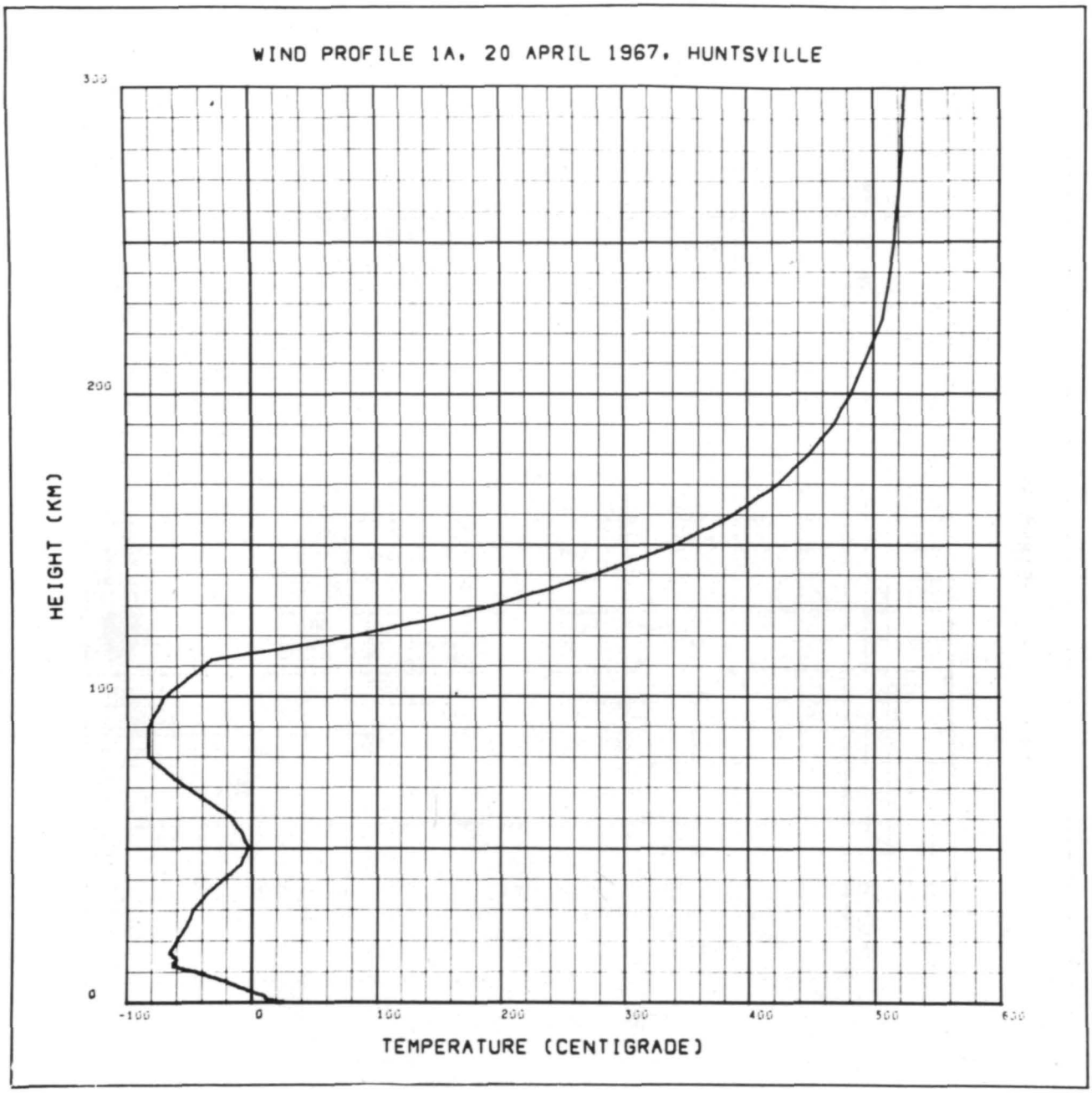


Figure 50: Acoustic ray-tracing input data:
height vs. temperature

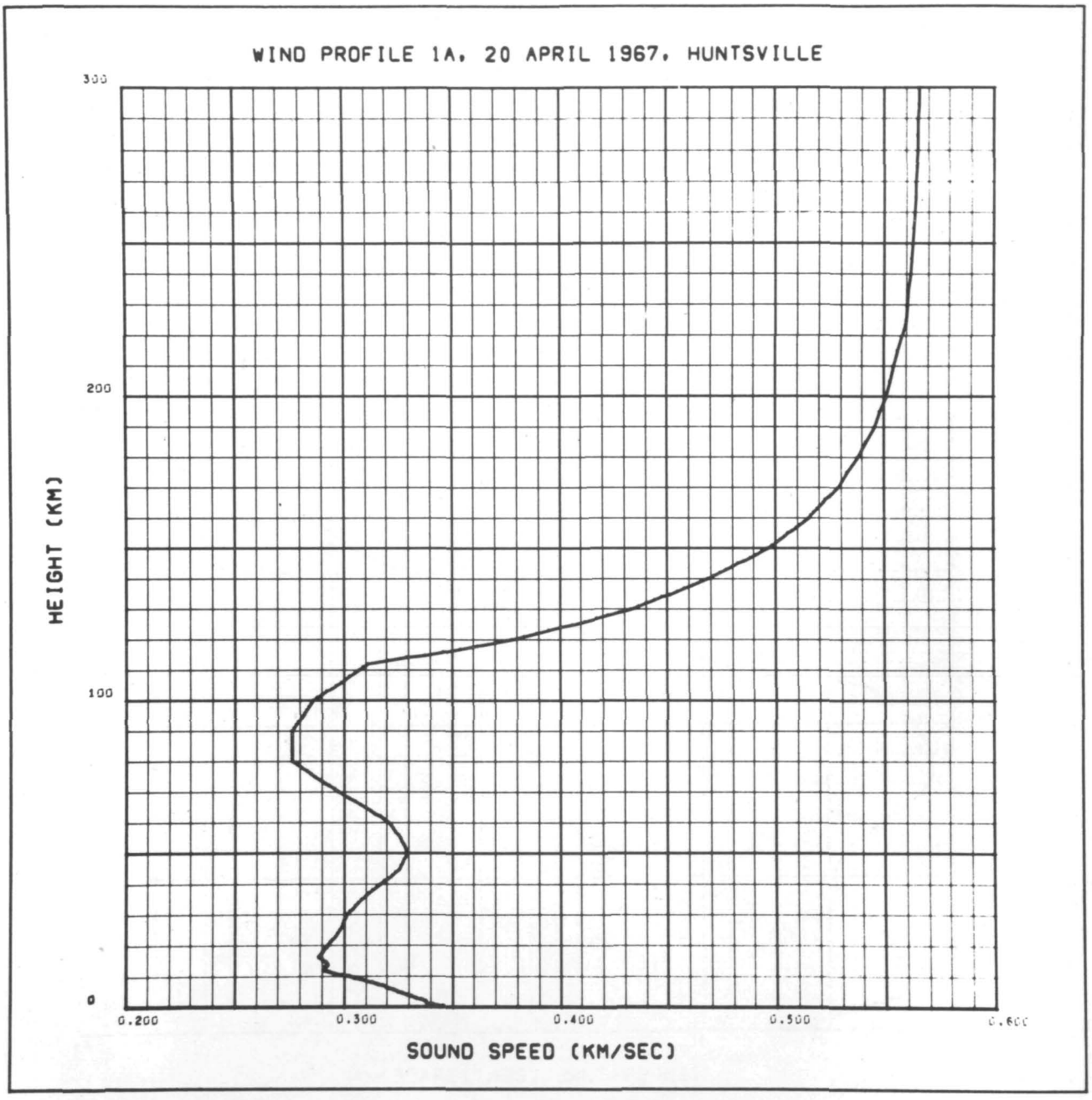


Figure 51: Acoustic ray-tracing input data: height vs. sound speed

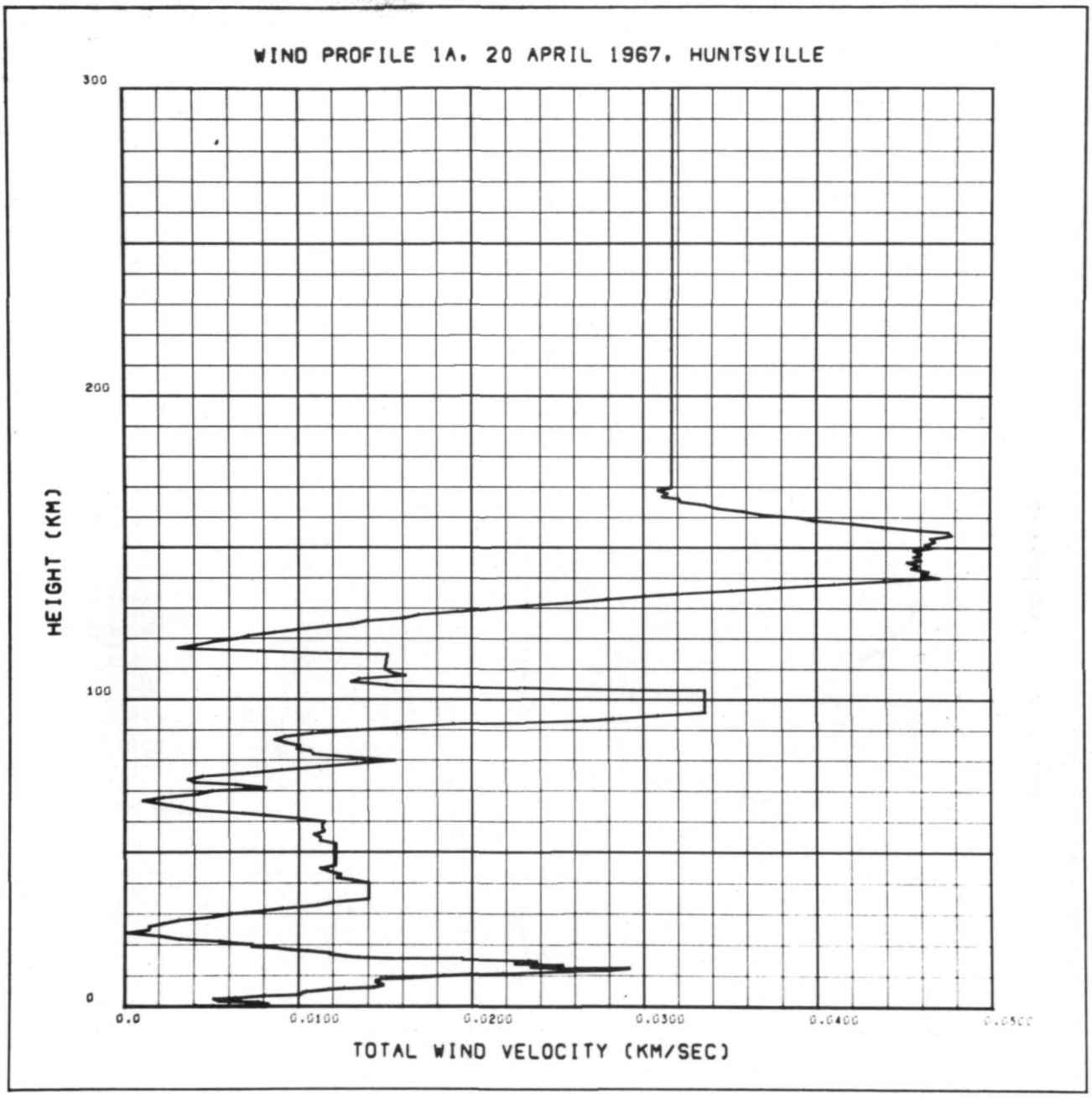


Figure 52: Acoustic ray-tracing input data: height vs. total wind velocity

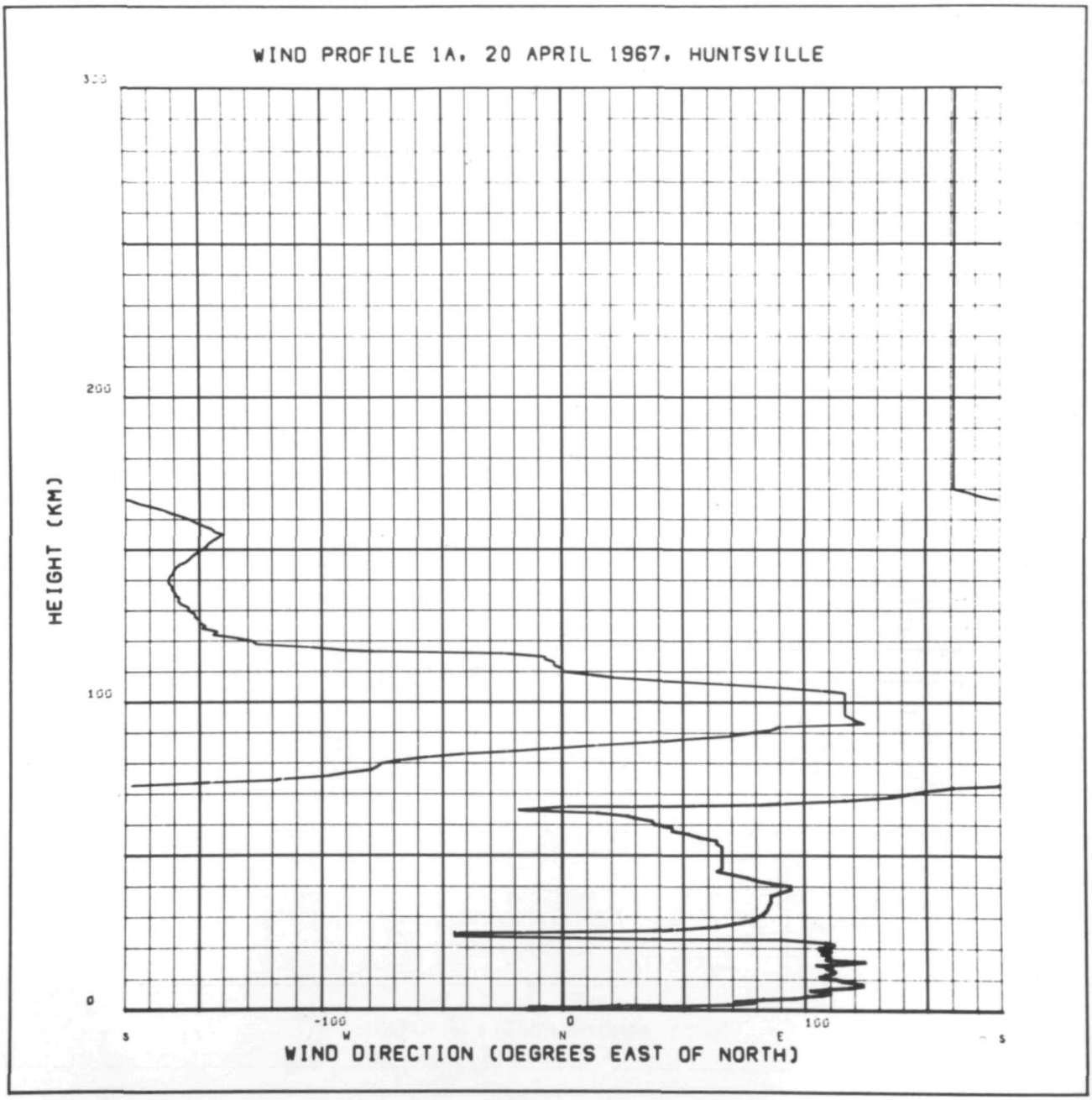


Figure 53: Acoustic ray-tracing input data: height vs. wind direction

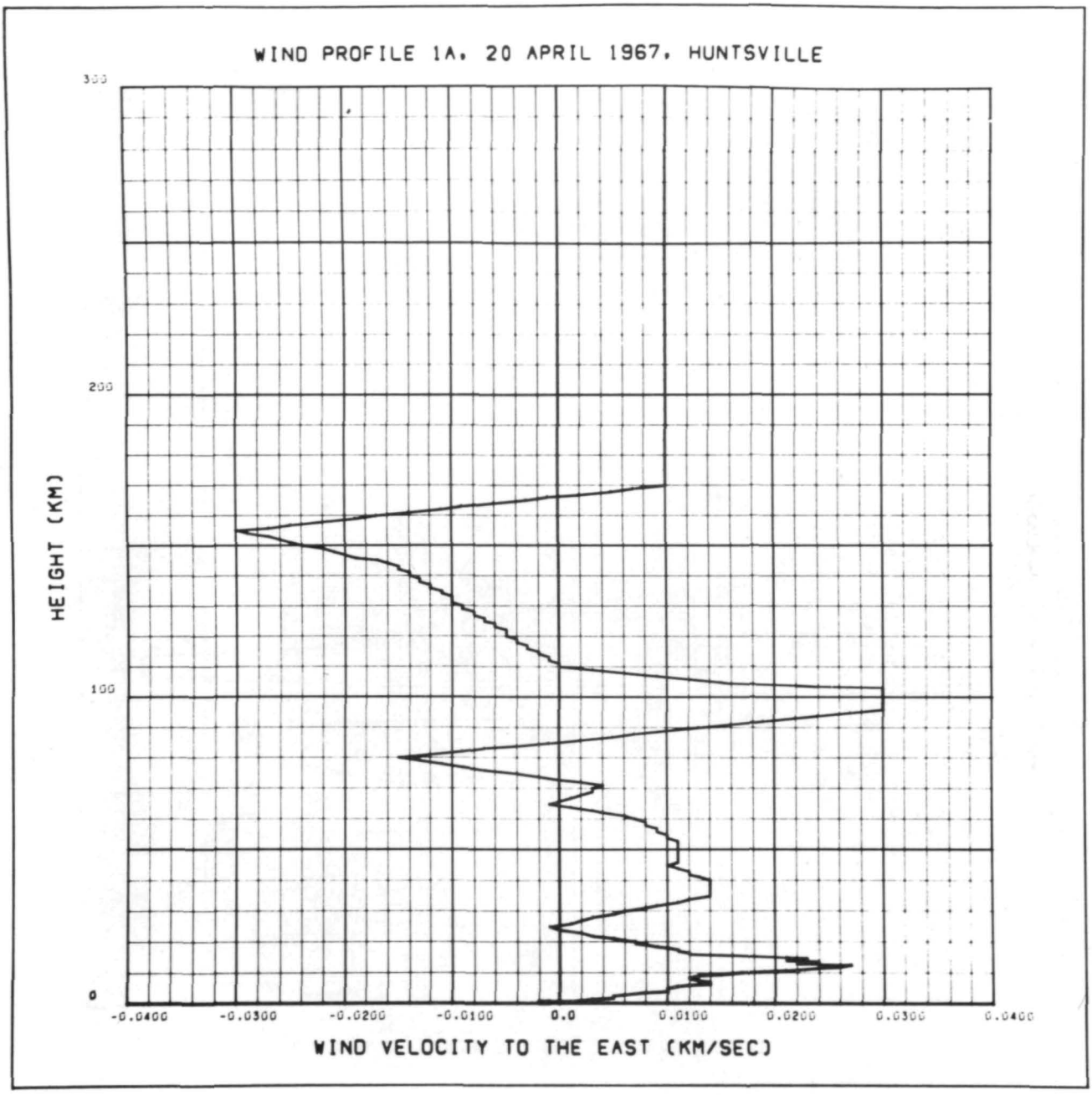


Figure 54: Acoustic ray-tracing input data: height vs. x-component of wind velocity

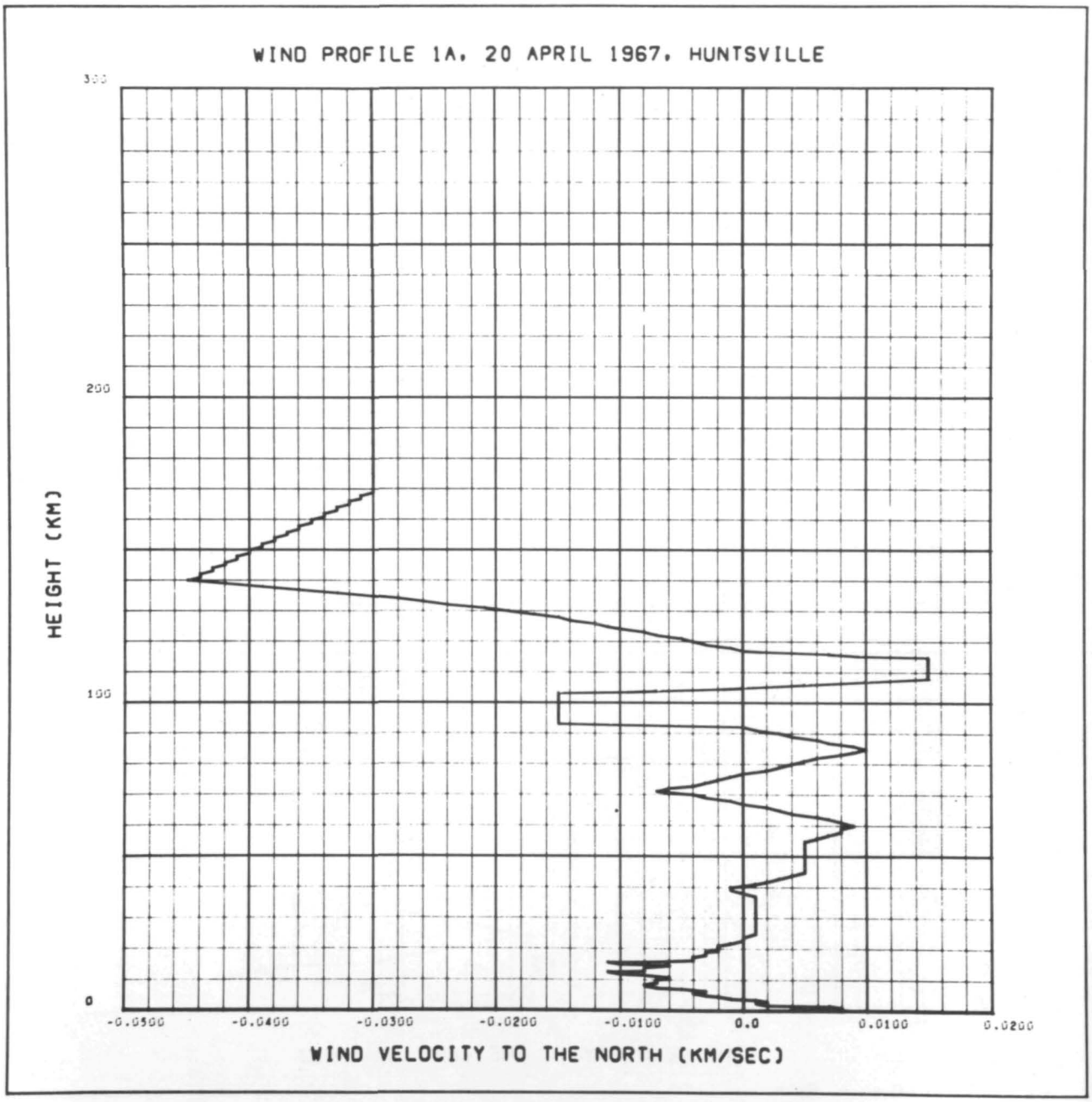


Figure 55: Acoustic ray-tracing input data: height vs. y-component of wind velocity

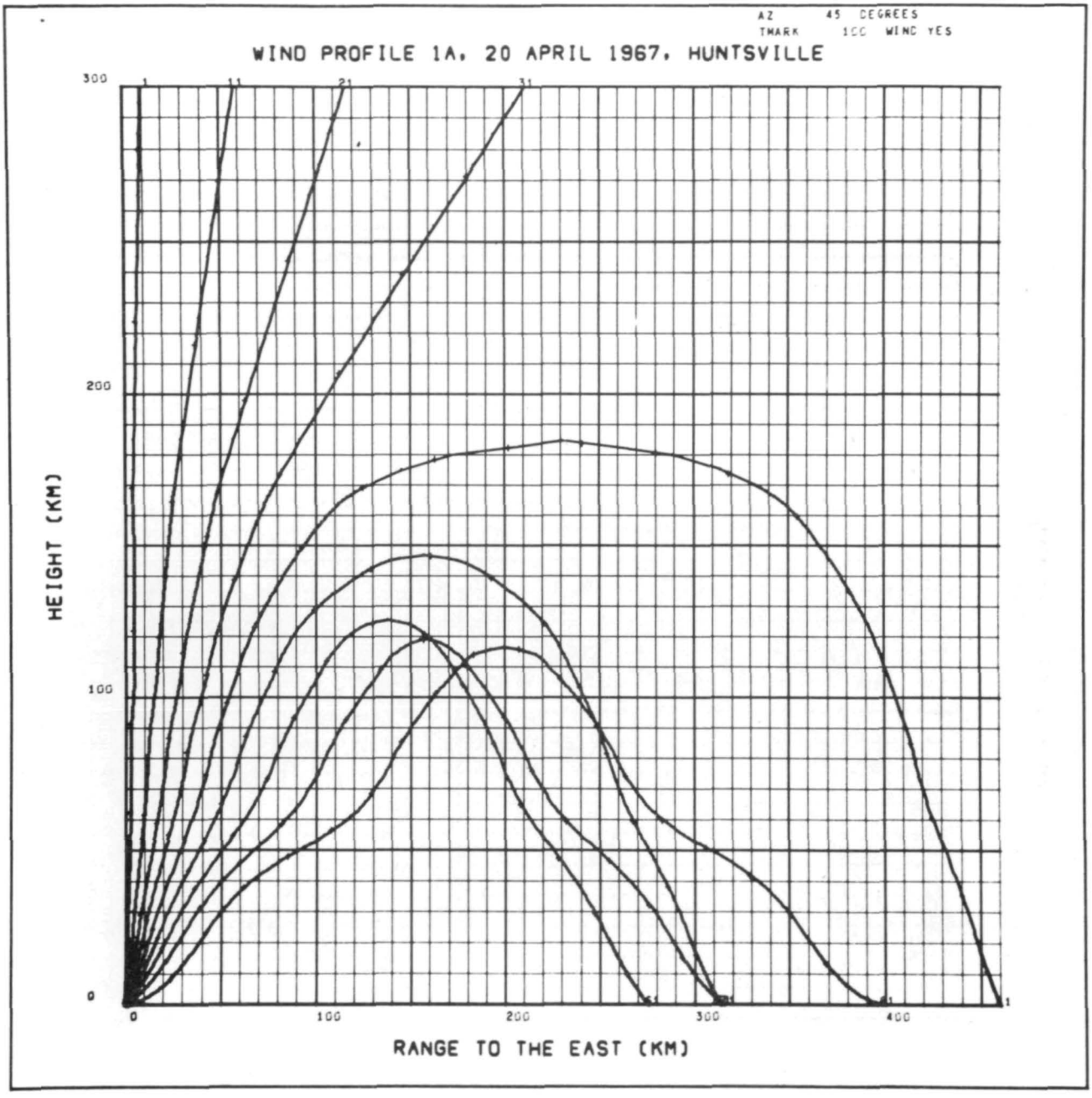


Figure 56: Acoustic ray-tracing output data: height vs. x-distance

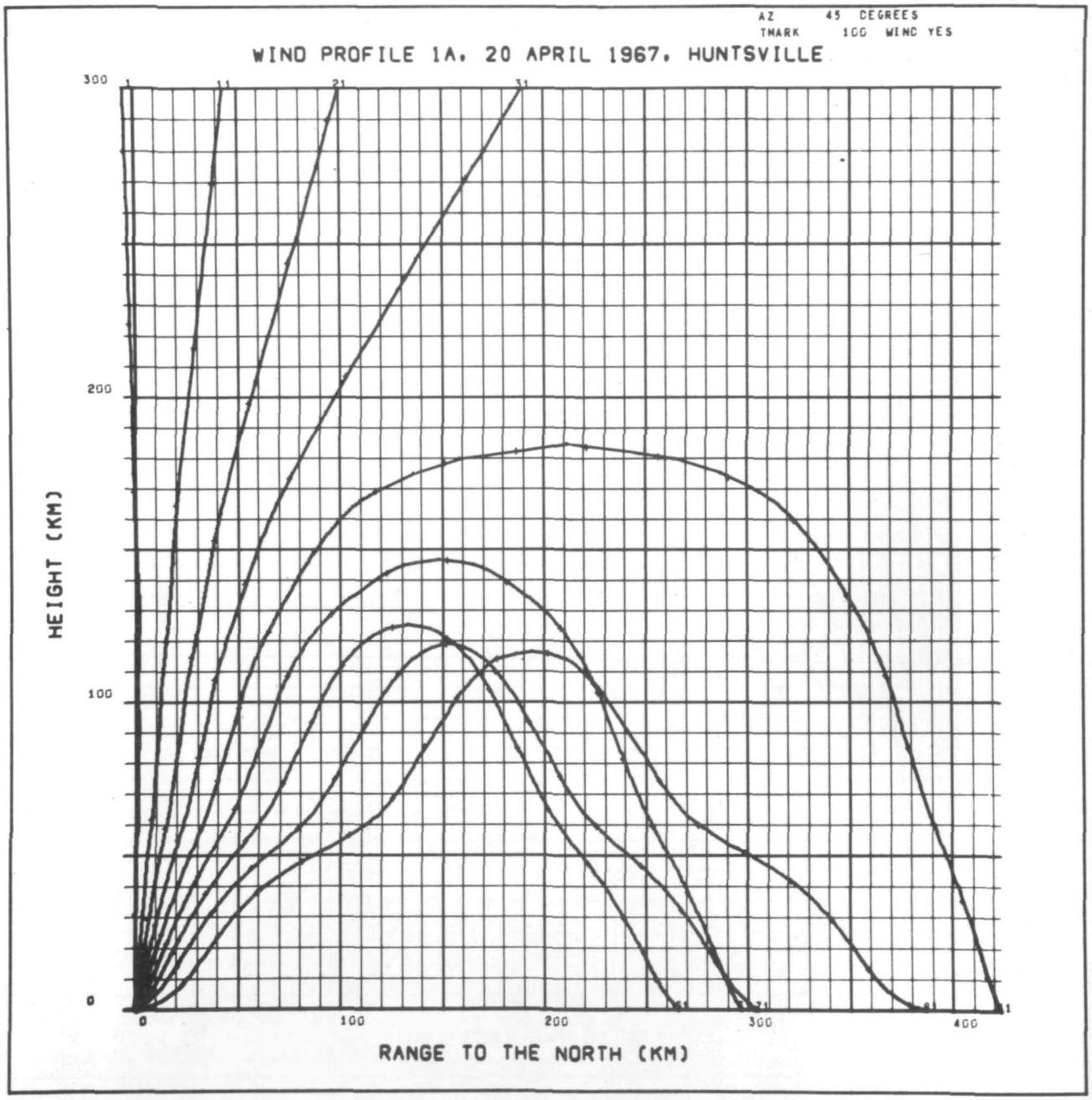


Figure 57: Acoustic ray-tracing output data: height vs. y-distance

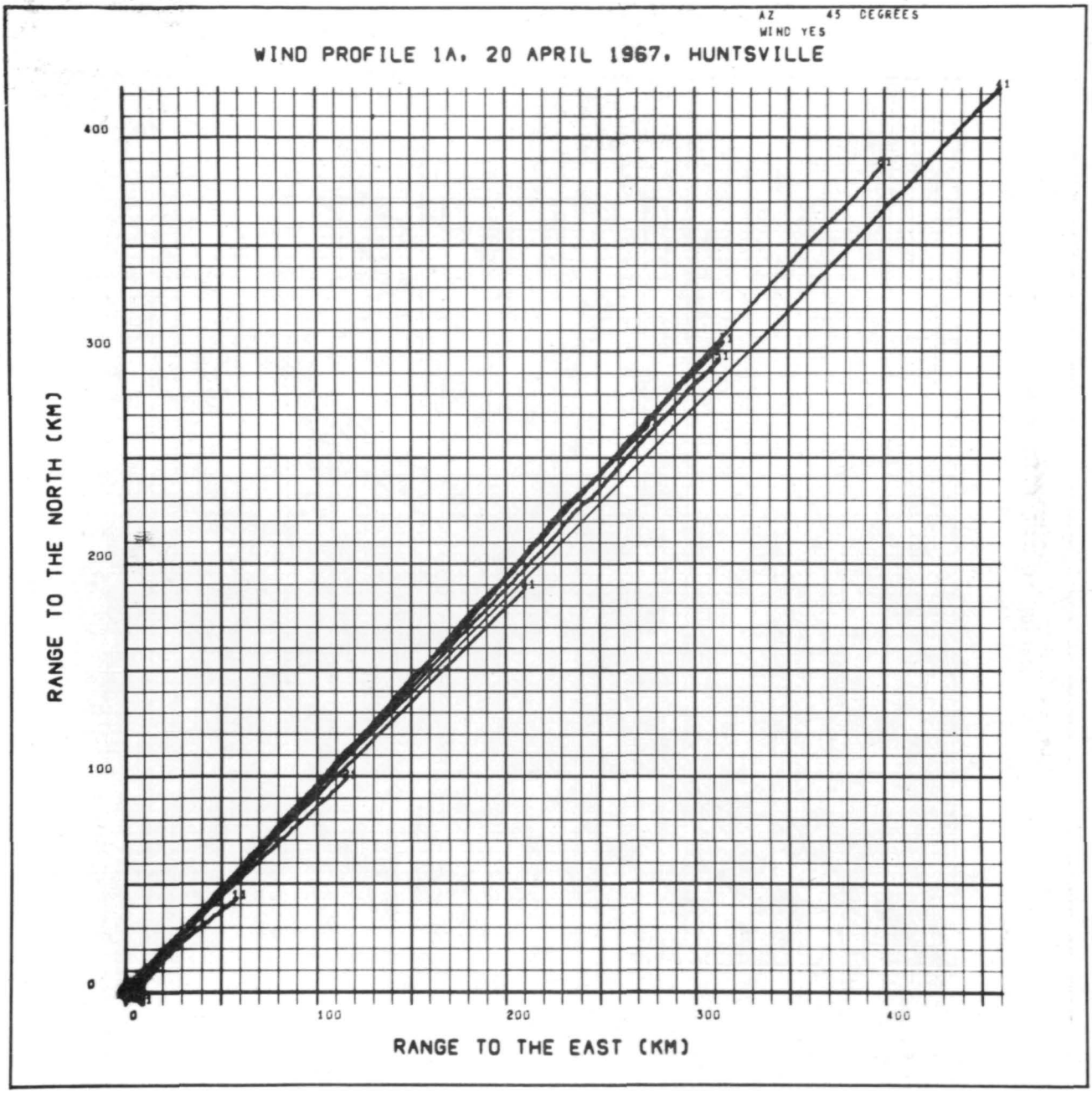


Figure 58: Acoustic ray-tracing output data:
y-distance vs. x-distance

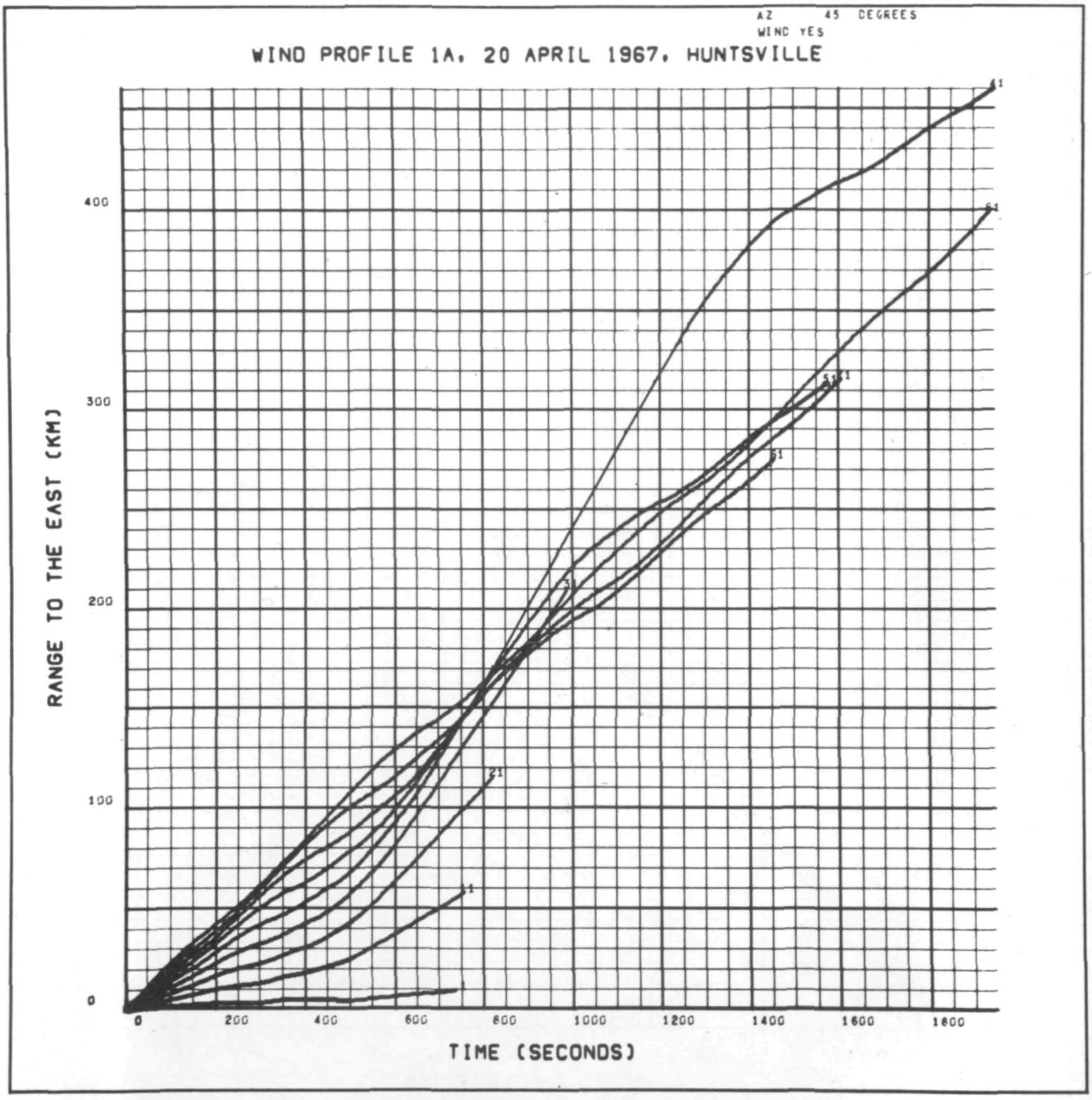


Figure 59: Acoustic ray-tracing output data:
x-distance vs. time

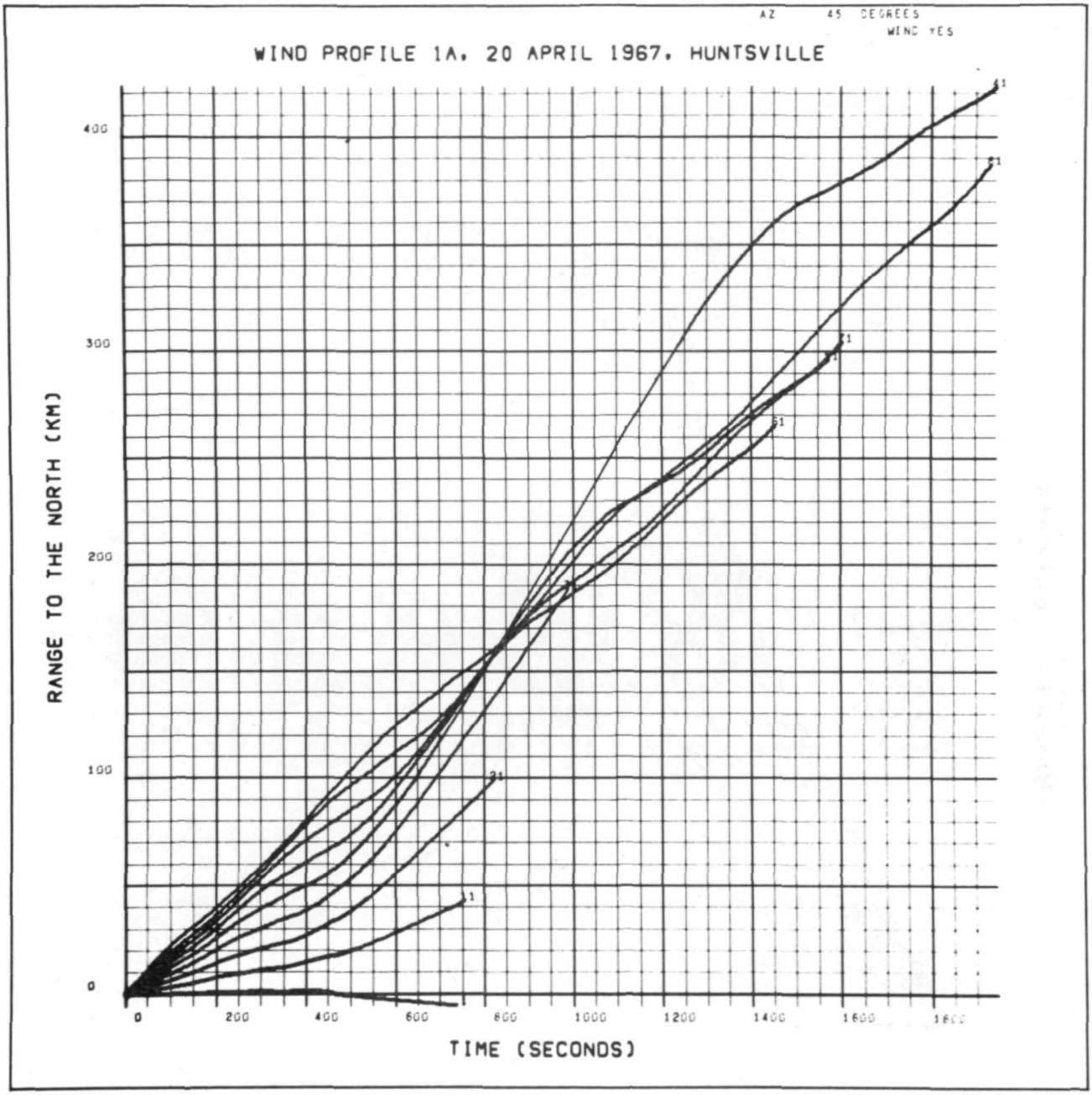


Figure 60: Acoustic ray-tracing output data:
y-distance vs. time

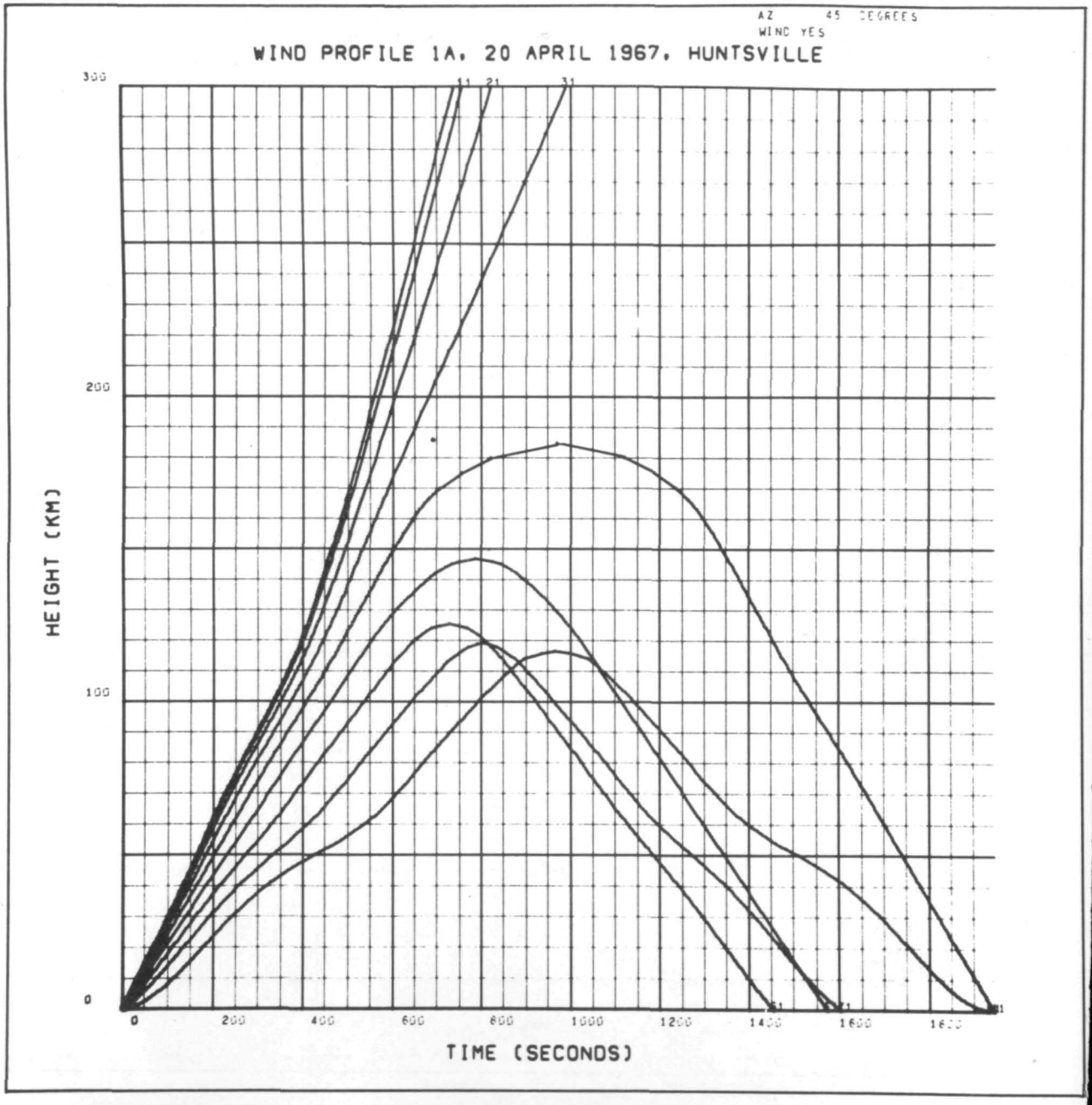


Figure 61: Acoustic ray-tracing output data: height vs. time

All the plots shown in Figures 50-61 are drawn and annotated automatically by the SC-4020 plotter. Detailed tabular printouts of the raypath trajectories are also optionally available.

6. Computer Program

A Fortran IV listing of the program for the Avco IBM 360/75 computer and detailed flow charts of each section of the program are included at the end of this appendix.

FORTRAN IV LISTING OF
ACOUSTIC RAY-TRACING COMPUTER PROGRAM

```
      IMPLICIT REAL *8(A-H,O-Z)                                          MAN00010
C                                                                        MAN00020
C     ACOUSTIC RAY-TRACING                                               MAN00030
C                                                                        MAN00040
C     L8074  R1748210000  Z230  DETERT/WEINSTEIN  1/68                   MAN00050
C     MOD. OF L8032                                                      MAN00060
C     REF- GEOMETRICAL ACOUSTICS' THEORY OF WAVES FROM A POINT SOURCE    MAN00070
C          IN A TEMPERATURE AND WIND-STRATIFIED ATMOSPHERE               MAN00080
C             BY ALLAN PIERCE  AVSSD-0135-66-CR  2AUG66                  MAN00090
C                                                                        MAN00100
C     SUBROUTINES                                                        MAN00110
C                                                                        MAN00120
C       PARAM                                                            MAN00130
C       DNDIST                                                           MAN00140
C       SKDIST                                                           MAN00150
C       ARTLU                                                            MAN00160
C       DEREQ
C       ADM4RK
C                                                                        MAN00170
C                                                                        MAN00180
      COMMON/FAYE/CI(300),VXI(300),VYI(300),ZI(300),PLXT(600),PLYZ(600),MAN00190
     1    PLYX(600),PLYY(600)                                            MAN00200
      COMMON/JANET/NMAX,NPLT                                             MAN00210
      COMMON/PEARL/ZTOP,ITOP,XTOP,YTOP,T2,X2,Y2                          MAN00220
      DIMENSION TITLE(9),VTIX(600),VTI(300),WDI(300),PLDCDZ(300)         MAN00230
      DIMENSION TEMQ(300), ORDTM(9)                                      MAN00240
      EQUIVALENCE (VTIX(1),VTI(1)),(VTIX(301),TEMQ(1))                   MAN00250
      DIMENSION ABSCP(9),ORDPX(9),ORDPY(9),ORDPT(9),ORDPC(9),ABSCT(9),   MAN00260
     1    ORDZZ(9),ORDXX(9),ORDYY(9),ABWD(9),ABVT(9),ABK(9),ORDC(9)      MAN00270
      REAL *4 INTABQ(300)                                                MAN00280
C                                                                        MAN00290
      CALL MIBCOM                                                        MAN00300
      CALL IDERMV('S.WEINSTEIN ','P1','L8074    ')                       MAN00310
      REWIND 13                                                          MAN00320
C                                                                        MAN00330
      DATA ABSCP/2*'         ','Z       ',6*'         '/                MAN00340
      DATA ORDTM/2*'         ','TEMP    ',6*'         '/                MAN00350
      DATA ORDPX/2*'         ','VX      ',6*'         '/                MAN00360
      DATA ORDPY/2*'         ','VY      ',6*'         '/                MAN00370
      DATA ORDPC/2*'         ','C       ',6*'         '/                MAN00380
      DATA ABSCT/2*'         ','TIME    ',6*'         '/                MAN00390
      DATA ORDZZ/2*'         ','Z       ',6*'         '/                MAN00400
      DATA ORDYY/2*'         ','Y       ',6*'         '/                MAN00410
      DATA ORDXX/2*'         ','X       ',6*'         '/                MAN00420
      DATA ABK /2*'         ','K       ',6*'         '/                MAN00430
      DATA ABWD/2*'         ','WD      ',6*'         '/                MAN00440
      DATA ABVT/2*'         ','VT      ',6*'         '/                MAN00450
      DATA ORDC/2*'         ','DC/DZ   ',6*'         '/                MAN00460
      DATA KXP,KYP,NDP,NVP,NSP,NCP,NGP,NXOP,NYOP/                        MAN00470
     1     0,  0,  1,  2,  1, 42,  1,   1,   1/                         MAN00480
      DATA INCOL1/8888/                                                  MAN00490
      TMARK = 1.0D&2                                                     MAN00500
      ITEST=0                                                            MAN00510
      CCONST=1.4D0*8.3144D-3/29.0D0                                      MAN00520
      NCARDS=1                                                           MAN00530
      DEGRAD=0.01745329D0                                                MAN00540
      RADDEG=57.2957795D0                                                MAN00550
      TCK=273.0D0                                                        MAN00560
```

```
      NTAB=1                                                            MAN005
      ITHETI=1                                                          MAN005
      ITHETF=89                                                         MAN005
      ITHETS=1                                                          MAN006
      NOPTN=1                                                           MAN006
      LD=1                                                              MAN006
      LS=1                                                              MAN006
      PHII=45.0D0                                                       MAN006
      ZS=0.0D0                                                          MAN006
      TS=0.0D0                                                          MAN006
      XS=0.0D0                                                          MAN006
      YS=0.0D0                                                          MAN006
      CALL WHERE(INTAB0)                                                MAN006
C                                                                       MAN007
      CALL SETUP(8HITHETAI  ,4,ITHETI      )                            MAN007
      CALL SETUP(8HITHETAF  ,4,ITHETF      )                            MAN007
      CALL SETUP(8HITHETAST,4,ITHETS       )                            MAN007
      CALL SETUP(8HPHI      ,8,PHII        )                            MAN007
      CALL SETUP(8HZS       ,8,ZS          )                            MAN007
      CALL SETUP(8HTS       ,8,TS          )                            MAN007
      CALL SETUP(8HXS       ,8,XS          )                            MAN007
      CALL SETUP(8HYS       ,8,YS          )                            MAN007
      CALL SETUP(8HNOPTN    ,4,NOPTN       )                            MAN007
      CALL SETUP(8HTMARK    ,8,TMARK     )                              MAN008
C                                                                       MAN008
C     READ AND WRITE INPUT TABLE                                        MAN008
C                                                                       MAN008
      WRITE(6,1)                                                        MAN008
      READ(5,2) TITLE                                                   MAN008
      WRITE(6,3) TITLE                                                  MAN008
C                                                                       MAN008
  110 READ(5,4) ITEST,ZI(NCARDS),VXI(NCARDS),VYI(NCARDS),TEMQ(NCARDS)   MAN008
      IF(ITEST.EQ.9) GO TO 130                                          MAN008
C                                                                       MAN008
      CI(NCARDS)=DSQRT(CCONST*(TEMQ(NCARDS) & TCK))                     MAN008
      VXISQ = VXI(NCARDS)*VXI(NCARDS)                                   MAN008
      VYISQ = VYI(NCARDS)*VYI(NCARDS)                                   MAN008
      VTI(NCARDS) =  SQRT(VXISQ & VYISQ)                                MAN008
      WDI(NCARDS) = DATAN2(VXI(NCARDS),VYI(NCARDS)) *RADDEG             MAN008
      WRITE(6,5) NCARDS,ZI(NCARDS),VXI(NCARDS),VYI(NCARDS),             MAN008
     1           TEMQ(NCARDS),CI(NCARDS)                                MAN008
      NCARDS=NCARDS & 1                                                 MAN008
      IF(NCARDS.LE.300) GO TO 110                                       MAN008
C                                                                       MAN010
      WRITE(6,6)                                                        MAN010
      GO TO 1000                                                        MAN010
C                                                                       MAN010
  130 NCARDS=NCARDS - 1                                                 MAN010
C                                                                       MAN010
      DO 120 I=2,NCARDS                                                 MAN010
      J = I - 1                                                         MAN010
      PLDCDZ(J) = (-CI(J) & CI(I))/(ZI(I) - ZI(J))                      MAN010
  120 CONTINUE                                                          MAN010
C                                                                       MAN010
      PLDCDZ(NCARDS) = PLDCDZ(NCARDS - 1)                               MAN010
C                                                                       MAN010
      NMAX=NCARDS                                                       MAN010
C                                                                       MAN010
```

```
      NPP=NMAX                                                          MAN01150
      NEP=1                                                             MAN01160
      DCXP=16.0D0                                                       MAN01170
      DCYP=16.0D0                                                       MAN01180
      CALL  AICRT3(KXP,KYP,  VXI,    ZI,NPP,NDP,NVP,NSP,NCP, TITLE,     MAN01190
     $   ORDPX, ABSCP,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)      MAN01200
      CALL  AICRT3(KXP,KYP,  VYI,   ZI ,NPP,NDP,NVP,NSP,NCP, TITLE,     MAN01210
     $   ORDPY, ABSCP,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)      MAN01220
      CALL  AICRT3(KXP,KYP,   CI,    ZI,NPP,NDP,NVP,NSP,NCP, TITLE,     MAN01230
     $   ORDPC, ABSCP,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)      MAN01240
      CALL  AICRT3(KXP,KYP,  VTI,    ZI,NPP,NDP,NVP,NSP,NCP, TITLE,     MAN01250
     $    ABVT, ABSCP,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)      MAN01260
      CALL  AICRT3(KXP,KYP,  WDI,    ZI,NPP,NDP,NVP,NSP,NCP, TITLE,     MAN01270
     $   ABWD , ABSCP,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)      MAN01280
      CALL  AICRT3(KXP,KYP,   ZI,PLDCDZ,NPP,NDP,NVP,NSP,NCP, TITLE,     MAN01290
     $   ABSCP, ORDC, NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)      MAN01300
      CALL  AICRT3(KXP,KYP, TEMQ,    ZI,NPP,NDP,NVP,NSP,NCP, TITLE,     MAN01310
     $   ORDTM,ORDZZ, NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)      MAN01320
                                                                        MAN01330
2000  CONTINUE                                                          MAN01340
      WRITE(6,7)                                                        MAN01350
                                                                        MAN01360
      CALL READIN(INCOL1,$1000)                                         MAN01370
                                                                        MAN01380
      PHI=PHII*DEGRAD                                                   MAN01390
                                                                        MAN01400
      LOOP FOR INCREMENTED THETA                                        MAN01410
                                                                        MAN01420
      DO  150  I=ITHETI,ITHETF,ITHETS                                   MAN01430
      AI=I*DEGRAD                                                       MAN01440
      CALL ARTLU(NTAB,ZS,ZI,CZ,CI)                                      MAN01450
      AKX=DSIN(AI)*DCOS(PHI)/CZ                                         MAN01460
      AKY=DSIN(AI)*DSIN(PHI)/CZ                                         MAN01470
      LS=1                                                              MAN01480
      NPLT=0                                                            MAN01490
                                                                        MAN01500
      CALL SKDIST(NOPTN,ZS,TS,XS,YS,AKX,AKY,TTOTS,XTOTS,YTOTS,LS)       MAN01510
                                                                        MAN01520
                                                                        MAN01530
      IF(LS.LT.0)  GO TO 132                                            MAN01540
                                                                        MAN01550
      ZSDN = PLYZ(NPLT)                                                 MAN01560
      NPLT = NPLT & 1                                                   MAN01570
      PLYZ(NPLT) = ZTOP                                                 MAN01580
      PLYT(NPLT) = TTOP                                                 MAN01590
      PLYX(NPLT) = XTOP                                                 MAN01600
      PLYY(NPLT) = YTOP                                                 MAN01610
      NPLT = NPLT & 1                                                   MAN01620
      PLYZ(NPLT) = ZSDN                                                 MAN01630
      PLYT(NPLT) = TTOTS                                                MAN01640
      PLYX(NPLT) = XTOTS                                                MAN01650
      PLYY(NPLT) = YTOTS                                                MAN01660
                                                                        MAN01670
      L=LS                                                              MAN01680
      AKR=AKX                                                           MAN01690
      AKS=AKY                                                           MAN01700
      CALL DNDIST(NOPTN,      ZSDN,TTOTS,XTOTS,YTOTS,AKR,AKS,TTOTS,XTOTSMAN01710
     $          ,YTOTS,L)                                             MAN01720
```

```
  132 CONTINUE                                                          MANO
      THETA=I                                                           MANO
      WRITE(6,9) THETA,PHII,TTOTS,XTOTS,YTOTS                          MANO
C                                                                      MANO
      NPP=NPLT                                                         MANO
      DPLT=I                                                           MANO
      CALL  AICRT3(KXP,KYP, PLXT,  PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,   MANO
     $   ABSCT, ORDZZ,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)     MANO
      CALL PRINTV(3,'EL ',718,1015)                                    MANO
      CALL LABLV(DPLT,750,1015,6,1,4)                                  MANO
      CALL PRINTV(   8,' DEGREES',806,1015)                            MANO
      CALL PRINTV(3,'AZ ',718, 999)                                    MANO
      CALL LABLV(PHII,750,999,6,1,4)                                   MANO
      CALL PRINTV(8,' DEGREES',806, 999)                               MANO
C                                                                      MANO
      CALL  AICRT3(KXP,KYP, PLXT,  PLYX,NPP,NDP,NVP,NSP,NCP, TITLE,   MANO
     $   ABSCT, ORDXX,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)     MANO
      CALL PRINTV(3,'EL ',718,1015)                                    MANO
      CALL LABLV(DPLT,750,1015,6,1,4)                                  MANO
      CALL PRINTV(   8,' DEGREES',806,1015)                            MANO
      CALL PRINTV(3,'AZ ',718, 999)                                    MANO
      CALL LABLV(PHII,750,999,6,1,4)                                   MANO
      CALL PRINTV(8,' DEGREES',806, 999)                               MANO
C                                                                      MANO
      CALL  AICRT3(KXP,KYP, PLXT,  PLYY,NPP,NDP,NVP,NSP,NCP, TITLE,   MANO
     $   ABSCT, ORDYY,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)     MANO
      CALL PRINTV(3,'EL ',718,1015)                                    MANO
      CALL LABLV(DPLT,750,1015,6,1,4)                                  MANO
      CALL PRINTV(   8,' DEGREES',806,1015)                            MANO
      CALL PRINTV(3,'AZ ',718, 999)                                    MANO
      CALL LABLV(PHII,750,999,6,1,4)                                   MANO
      CALL PRINTV(8,' DEGREES',806, 999)                               MANO
C                                                                      MANO
      CALL  AICRT3(KXP,KYP, PLYX,  PLYY,NPP,NDP,NVP,NSP,NCP, TITLE,   MANO
     $   ORDXX, ORDYY,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)     MANO
C                                                                      MANO
      CALL PRINTV(3,'EL ',718,1015)                                    MANO
      CALL LABLV(DPLT,750,1015,6,1,4)                                  MANO
      CALL PRINTV(   8,' DEGREES',806,1015)                            MANO
      CALL PRINTV(3,'AZ ',718, 999)                                    MANO
      CALL LABLV(PHII,750,999,6,1,4)                                   MANO
      CALL PRINTV(8,' DEGREES',806, 999)                               MANO
C                                                                      MANO
      CALL  AICRT3(KXP,KYP, PLYX,  PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,   MANO
     $   ORDXX, ORDZZ,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)     MANO
C                                                                      MANO
      CALL PRINTV(3,'EL ',718,1015)                                    MANO
      CALL LABLV(DPLT,750,1015,6,1,4)                                  MANO
      CALL PRINTV(   8,' DEGREES',806,1015)                            MANO
      CALL PRINTV(3,'AZ ',718, 999)                                    MANO
      CALL LABLV(PHII,750,999,6,1,4)                                   MANO
      CALL PRINTV(8,' DEGREES',806, 999)                               MANO
C                                                                      MANO
      CALL  AICRT3(KXP,KYP, PLYY,  PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,   MANO
     $   ORDYY, ORDZZ,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)     MANO
      CALL PRINTV(3,'EL ',718,1015)                                    MANO
      CALL LABLV(DPLT,750,1015,6,1,4)                                  MANO
      CALL PRINTV(   8,' DEGREES',806,1015)                            MANO
```

```
      CALL PRINTV(3,'AZ ',718, 999)                                    MAN02310
      CALL LABLV(PHII,750,999,6,1,4)                                   MAN02320
      CALL PRINTV(8,' DEGREES',806, 999)                               MAN02330
                                                                       MAN02340
      DO 133 IIQ=1,NPLT                                                MAN02350
      PLYXSQ = PLYX(IIQ)*PLYX(IIQ)                                     MAN02360
      PLYYSQ = PLYY(IIQ)*PLYY(IIQ)                                     MAN02370
      VTIX(IIQ) = SQRT(PLYXSQ & PLYYSQ)                                MAN02380
  133 CONTINUE                                                         MAN02390
                                                                       MAN02400
      CALL  AICRT3(KXP,KYP, VTIX,  PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,   MAN02410
     $     ABK, ORDZZ,NEP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)     MAN02420
                                                                       MAN02430
      CALL PRINTV(3,'EL ',718,1015)                                    MAN02440
      CALL LABLV(DPLT,750,1015,6,1,4)                                  MAN02450
      CALL PRINTV(  8,' DEGREES',806,1015)                             MAN02460
      CALL PRINTV(3,'AZ ',718, 999)                                    MAN02470
      CALL LABLV(PHII,750,999,6,1,4)                                   MAN02480
      CALL PRINTV(8,' DEGREES',806, 999)                               MAN02490
                                                                       MAN02500
                                                                       MAN02510
                                                                       MAN02520
      IF(I.NE.ITHETI) GO TO 135                                        MAN02530
                                                                       MAN02540
      PLYZMX = PLYZ(1)                                                 MAN02550
      PLYXMX = PLYX(1)                                                 MAN02560
      PLYYMX = PLYY(1)                                                 MAN02570
      PLYVMX = VTIX(1)                                                 MAN02580
      PLYZMN = PLYZ(1)                                                 MAN02590
      PLYXMN = PLYX(1)                                                 MAN02600
      PLYYMN = PLYY(1)                                                 MAN02610
      PLYVMN = VTIX(1)                                                 MAN02620
      XTMAX = PLXT(NPP)                                                MAN02630
      XTMIN = PLXT(1)                                                  MAN02640
      GO TO 137                                                        MAN02650
                                                                       MAN02660
  135 CONTINUE                                                         MAN02670
      XTMAX = DMAX1(XTMAX,PLXT(NPP))                                   MAN02680
      XTMIN = DMIN1(XTMIN,PLXT(1))                                     MAN02690
                                                                       MAN02700
  137 CONTINUE                                                         MAN02710
                                                                       MAN02720
      DO 140 II=1,NPP                                                  MAN02730
      PLYZMX = DMAX1(PLYZ(II),PLYZMX)                                  MAN02740
      PLYXMX = DMAX1(PLYX(II),PLYXMX)                                  MAN02750
      PLYYMX = DMAX1(PLYY(II),PLYYMX)                                  MAN02760
      PLYVMX = DMAX1(VTIX(II),PLYVMX)                                  MAN02770
      PLYZMN = DMIN1(PLYZ(II),PLYZMN)                                  MAN02780
      PLYXMN = DMIN1(PLYX(II),PLYXMN)                                  MAN02790
      PLYYMN = DMIN1(PLYY(II),PLYYMN)                                  MAN05210
      PLYVMN = DMIN1(VTIX(II),PLYVMN)                                  MAN05220
  140 CONTINUE                                                         MAN05230
                                                                       MAN05240
      WRITE(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX                           MAN05250
                                                                       MAN05260
  150 CONTINUE                                                         MAN05270
                                                                       MAN05280
                                                                       MAN05290
```

```
C     PLOT COMPOSIT GRAPHS                                                MAN053
C                                                                         MAN053
      END FILE 13                                                         MAN053
      REWIND 13                                                           MAN053
      NFP=1                                                               MAN053
C                                                                         MAN053
      NXOP=2                                                              MAN053
      NYOP=2                                                              MAN053
      XLP = XTMIN                                                         MAN053
      XUP = XTMAX                                                         MAN053
      YLP = PLYZMN                                                        MAN054
      YUP = PLYZMX                                                        MAN054
C                                                                         MAN054
      DO   200  I=ITHETI,ITHETF,ITHETS                                    MAN054
      IF(I.GT.ITHETI) NFP=2                                               MAN054
      READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX                               MAN054
      CALL  AICRT3(KXP,KYP, PLXT,  PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,      MAN054
     $   ABSCT, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)       MAN054
  200 CONTINUE                                                            MAN054
C                                                                         MAN054
      REWIND 13                                                           MAN055
      CALL PRINTV(3,'AZ ',718,1015)                                       MAN055
      CALL LABLV(PHII,750,1015,6,1,4)                                     MAN055
      CALL PRINTV(8,' DEGREES',806,1015)                                  MAN055
C                                                                         MAN055
      NFP=1                                                               MAN055
      YLP = PLYXMN                                                        MAN055
      YUP = PLYXMX                                                        MAN055
C                                                                         MAN055
      DO  210 I=ITHETI,ITHETF,ITHETS                                      MAN055
      IF(I.GT.ITHETI) NFP=2                                               MAN056
      READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX                               MAN056
      CALL  AICRT3(KXP,KYP, PLXT,  PLYX,NPP,NDP,NVP,NSP,NCP, TITLE,      MAN056
     $   ABSCT, ORDXX,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)       MAN056
  210 CONTINUE                                                            MAN056
C                                                                         MAN056
      REWIND 13                                                           MAN056
      CALL PRINTV(3,'AZ ',718,1015)                                       MAN056
      CALL LABLV(PHII,750,1015,6,1,4)                                     MAN056
      CALL PRINTV(8,' DEGREES',806,1015)                                  MAN056
C                                                                         MAN057
      NFP=1                                                               MAN057
      YLP=PLYYMN                                                          MAN057
      YUP=PLYYMX                                                          MAN057
C                                                                         MAN057
      DO 220 I=ITHETI,ITHETF,ITHETS                                       MAN057
      IF(I.GT.ITHETI) NFP=2                                               MAN057
      READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX                               MAN057
      CALL  AICRT3(KXP,KYP, PLXT,  PLYY,NPP,NDP,NVP,NSP,NCP, TITLE,      MAN057
     $   ABSCT, ORDYY,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)       MAN057
  220 CONTINUE                                                            MAN058
C                                                                         MAN058
      REWIND 13                                                           MAN058
      CALL PRINTV(3,'AZ ',718,1015)                                       MAN058
      CALL LABLV(PHII,750,1015,6,1,4)                                     MAN058
      CALL PRINTV(8,' DEGREES',806,1015)                                  MAN058
C                                                                         MAN058
      NFP=1                                                               MAN058
```

```
      YLP = PLYZMN                                                      MAN05880
      YUP = PLYZMX                                                      MAN05890
      XLP = PLYXMN                                                      MAN05900
      XUP = PLYXMX                                                      MAN05910
C                                                                       MAN05920
      DO 230 I=ITHETI,ITHETF,ITHETS                                     MAN05930
      IF(I.GT.ITHETI) NFP=2                                             MAN05940
      READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX                             MAN05950
      CALL  AICRT3(KXP,KYP, PLYX,  PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,    MAN05960
     $   ORDXX, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)     MAN05970
      TMARKQ = PLXT(NPP)                                                MAN05980
      TMARKX = TMARK                                                    MAN05990
234   IF(TMARKX.GE.TMARKQ) GO TO 236                                    MAN06000
      CALL ARTLU(2,TMARKX,PLXT,YMARK,PLYZ,XMARK,PLYX)                   MAN06010
      CALL PLOTV(NXV(XMARK),NYV(YMARK),16)                              MAN06020
      TMARKX = TMARKX & TMARK                                           MAN06030
      GO TO 234                                                         MAN06040
236   CONTINUE                                                          MAN06050
230   CONTINUE                                                          MAN06060
C                                                                       MAN06070
      REWIND 13                                                         MAN06080
      CALL PRINTV(3,'AZ ',718,1015)                                     MAN06090
      CALL LABLV(PHII,750,1015,6,1,4)                                   MAN06100
      CALL PRINTV(8,' DEGREES',806,1015)                                MAN06110
      CALL PRINTV(6,'TMARK ',718,999)                                   MAN06120
      CALL LABLV(TMARK,774,999,6,1,4)                                   MAN06130
C                                                                       MAN06140
C                                                                       MAN06150
      NFP=1                                                             MAN06160
      XLP = PLYYMN                                                      MAN06170
      XUP = PLYYMX                                                      MAN06180
C                                                                       MAN06190
      DO 240 I=ITHETI,ITHETF,ITHETS                                     MAN06200
      IF(I.GT.ITHETI) NFP=2                                             MAN06210
      READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX                             MAN06220
      CALL  AICRT3(KXP,KYP, PLYY,  PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,    MAN06230
     $   ORDYY, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)     MAN06240
      TMARKQ = PLXT(NPP)                                                MAN06250
      TMARKX = TMARK                                                    MAN06260
244   IF(TMARKX.GE.TMARKQ) GO TO 246                                    MAN06270
      CALL ARTLU(2,TMARKX,PLXT,YMARK,PLYZ,XMARK,PLYY)                   MAN06280
      CALL PLOTV(NXV(XMARK),NYV(YMARK),16)                              MAN06290
      TMARKX = TMARKX & TMARK                                           MAN06300
      GO TO 244                                                         MAN06310
246   CONTINUE                                                          MAN06320
240   CONTINUE                                                          MAN06330
C                                                                       MAN06340
      REWIND 13                                                         MAN06350
      CALL PRINTV(3,'AZ ',718,1015)                                     MAN06360
      CALL LABLV(PHII,750,1015,6,1,4)                                   MAN06370
      CALL PRINTV(8,' DEGREES',806,1015)                                MAN06380
      CALL PRINTV(6,'TMARK ',718,999)                                   MAN06390
      CALL LABLV(TMARK,774,999,6,1,4)                                   MAN06400
C                                                                       MAN06410
C                                                                       MAN06420
      NFP=1                                                             MAN06430
      XLP = PLYVMN                                                      MAN06440
      XUP = PLYVMX                                                      MAN06450
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C                                                                       MAN06460
C     DO 250 I=ITHETI,ITHETF,ITHETS                                     MAN06470
C     IF(I.GT.ITHETI) NFP=2                                             MAN06480
C     READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX                             MAN06490
C     CALL  AICRT3(KXP,KYP, VTIX,  PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,    MAN06500
C    $     ABK, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)      MAN06510
C 250 CONTINUE                                                          MAN06520
C                                                                       MAN06530
C     REWIND 13                                                         MAN06540
C     CALL PRINTV(3,'AZ ',718,1015)                                     MAN06550
C     CALL LABLV(PHII,750,1015,6,1,4)                                   MAN06560
C     CALL PRINTV(8,' DEGREES',806,1015)                                MAN06570
C                                                                       MAN06580
      NFP = 1                                                           MAN06590
      XLP = PLYXMN                                                      MAN06600
      XUP = PLYXMX                                                      MAN06610
      YLP = PLYYMN                                                      MAN06620
      YUP = PLYYMX                                                      MAN06630
C                                                                       MAN06640
      DO 260 I=ITHETI,ITHETF,ITHETS                                     MAN06650
      IF(I.GT.ITHETI) NFP=2                                             MAN06660
      READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX                             MAN06670
      CALL  AICRT3(KXP,KYP, PLYX,  PLYY,NPP,NDP,NVP,NSP,NCP, TITLE,    MAN06680
     $   ORDXX, ORDYY,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)     MAN06690
  260 CONTINUE                                                          MAN06700
C                                                                       MAN06710
      REWIND 13                                                         MAN06720
      CALL PRINTV(3,'AZ ',718,1015)                                     MAN06730
      CALL LABLV(PHII,750,1015,6,1,4)                                   MAN06740
      CALL PRINTV(8,' DEGREES',806,1015)                                MAN06750
C                                                                       MAN06760
      GO TO 2000                                                        MAN06770
C                                                                       MAN06780
 1000 CONTINUE                                                          MAN06790
      CALL FRAMEV(0)                                                    MAN06800
      CALL PLTND                                                        MAN06810
C                                                                       MAN06820
    1 FORMAT('1ACCOUSTIC RAY-TRACING',/' ')                             MAN06830
    2 FORMAT(9A8)                                                       MAN06840
    3 FORMAT('0',9A8,//'  I',7X,'ZI',8X,'VXI',7X,'VYI',5X,'TEMP',8X,'CI'MAN06850
     $       ,/' ')                                                     MAN06860
    4 FORMAT(I1,4E10.0)                                                 MAN06870
    5 FORMAT(1X,I3,F10.1,3F10.3,F10.4)                                  MAN06880
    6 FORMAT(//'** TOO MANY CARDS FOR TABLE')                           MAN06890
    7 FORMAT('1')                                                       MAN06900
    9 FORMAT('0THETA      ',F10.1,/                                     MAN06910
     1       ' PHI        ',F10.1,/                                     MAN06920
     2       ' TOTAL TIME ',F10.1,/                                     MAN06930
     3       ' TOTAL X    ',F10.1,/                                     MAN06940
     4       ' TOTAL Y    ',F10.1)                                      MAN06950
C                                                                       MAN06960
      STOP                                                              MAN06970
      END                                                               MAN06980
        IMPLICIT REAL*8 (A-H,O-Z)                                       PAR00010
      SUBROUTINE PARAM(AKX,AKY,C,VX,VY,DTUP,DXUP,DYUP,AKZSQ)            PAR00020
      BOM=1.0-AKX*VX-AKY*VY                                             PAR00030
      DTUP=BOM/C**2                                                     PAR00040
      DXUP=AKX&VX*DTUP                                                  PAR00050
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      DYUP=AKY&VY*DTUP                                                  PAR00060
      AKZSQ=BOM*DTUP-AKX**2-AKY**2                                      PAR00070
      RETURN                                                            PAR00080
      END                                                               PAR00090
      IMPLICIT REAL*8 (A-H,O-Z)                                         SKD00010
C                                                                       SKD00020
      SUBROUTINE SKDIST(NOPTN,ZS,TS,XS,YS,AKX,AKY,TTOT,XTOT,YTOT,L)     SKD00030
C                                                                       SKD00040
C     MODIDIED FOR PREDICTOR CORRECTOR                                  SKD00050
      COMMON/FAYE/CI(300),VXI(300),VYI(300),ZI(300),PLXT(600),PLYZ(600),SKD00060
     1            PLYX(600),PLYY(600)                                   SKD00070
      COMMON/JANET/NMAX,NPLT                                            SKD00080
      COMMON/PEARL/ZTOP,TTOP,XTOP,YTOP,T2,X2,Y2                         SKD00090
      DIMENSION VALUE(3),DERN(3),UPBND(3),DNBND(3)                      SKD00100
      COMMON/JULIA/QAKX,QAKY                                            SKD00110
      RADDEG = 57.29577951310D0                                         SKD00130
      AKXKY = AKX*AKX & AKY*AKY                                         SKD00140
      QAKX = AKX                                                        SKD00150
      QAKY = AKY                                                        SKD00160
C                                                                       SKD00170
      IF(ZS.LT.ZI(NMAX)) GO TO 110                                      SKD00180
      WRITE(6,1) ZS,ZI(NMAX)                                            SKD00190
      CALL EXIT                                                         SKD00200
C                                                                       SKD00210
  110 CONTINUE                                                          SKD00220
C                                                                       SKD00230
      DO 120 I=2,NMAX                                                   SKD00240
      IF(ZS.LE.ZI(I))GO TO 130                                          SKD00250
  120 CONTINUE                                                          SKD00260
C                                                                       SKD00270
  130 IF(ZS.EQ.ZI(I)) I=I&1                                             SKD00280
      IXX=I                                                             SKD00290
      IF(ZS.GT.ZI(1)) GO TO 135                                         SKD00300
      VX = VXI(1)                                                       SKD00310
      VY = VYI(1)                                                       SKD00320
      C = CI(1)                                                         SKD00330
      GO TO 136                                                         SKD00340
  135 CONTINUE                                                          SKD00350
      CALL ARTLU(3,ZS,ZI,VX,VXI,VY,VYI,C,CI)                            SKD00360
  136 CONTINUE                                                          SKD00370
      TM1 = (1.0D0 - AKX*VX - AKY*VY)/C                                 SKD00380
      AK1SQ = TM1*TM1 - AKXKY                                           SKD00390
C                                                                       SKD00400
      IF(AK1SQ.GT.0.0D0) GO TO 140                                      SKD00410
      WRITE(6,2) Z1                                                     SKD00420
      L=-1                                                              SKD00440
      RETURN                                                            SKD00450
C                                                                       SKD00460
  140 WRITE(6,7) AKX,AKY                                                SKD00470
      WRITE(6,3)                                                        SKD00480
C                                                                       SKD00490
      INITIAL CONDITIONS                                                SKD00500
C                                                                       SKD00510
      NEQ = 3                                                           SKD00520
      DATA UPBND/1.0D-2,2*1.0D0/                                        SKD00530
      DNBND(1) = 1.0D-4                                                 SKD00540
      DNBND(2) = 1.0D-2                                                 SKD00550
      DNBND(3) = 1.0D-2                                                 SKD00560
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      FACTOR = .5D0                                                     SKD00570
      ZIND = ZS                                                         SKD00580
      DELMIT = 0.0D0                                                    SKD00590
      VALUE(1) = TS                                                     SKD00600
      VALUE(2) = XS                                                     SKD00610
      VALUE(3) = YS                                                     SKD00620
      WRITE(6,4) ZIND,VALUE                                             SKD00630
C                                                                       SKD00640
      DO  160  I=IXX,NMAX                                               SKD00650
      HLIMIT = ZI(I)                                                    SKD00660
      DEL = DABS(HLIMIT-ZIND) * 1.0D-1                                  SKD00670
      FREQ = 10.0D0*DEL                                                 SKD00680
      LQX = 1                                                           SKD00690
      IF(HLIMIT.GT.ZI(1)) GO TO 145                                     SKD00700
      VX = VXI(1)                                                       SKD00710
      VY = VYI(1)                                                       SKD00720
      C = CI(1)                                                         SKD00730
      GO TO 146                                                         SKD00740
  145 CONTINUE                                                          SKD00750
      CALL ARTLU(3,HLIMIT ,ZI,VX,VXI,VY,VYI,C,CI)                       SKD00760
  146 CONTINUE                                                          SKD00770
      TM1 = (1.0D0 - AKX*VX - AKY*VY)/C                                 SKD00780
      AK2SQ = TM1*TM1 - AKXKY                                           SKD00790
      IF(AK2SQ.LE.0.0D0) GO TO 180                                      SKD00800
  150 CONTINUE                                                          SKD00810
  155 CALL ADM4RK(NEQ,DEL,VALUE,DERN,UPBND,DNBND,FACTOR,FREQ,HLIMIT,    SKD00820
     1             LQX,ZIND,DELMIT)                                     SKD00830
      GO TO(155,155,157,157,155,156),LQX                                SKD00840
  156 WRITE(6,9) DEL                                                    SKD00850
      L= -1                                                             SKD00860
      RETURN                                                            SKD00870
C                                                                       SKD00880
  157 CONTINUE                                                          SKD00890
      NPLT = NPLT + 1                                                   SKD00900
      PLXT(NPLT) = VALUE(1)                                             SKD00910
      PLYX(NPLT) = VALUE(2)                                             SKD00920
      PLYY(NPLT) = VALUE(3)                                             SKD00930
      PLYZ(NPLT) = ZIND                                                 SKD00940
      CALL ARTLU(2,ZIND,ZI,VX,VXI,VY,VYI)                               SKD00950
      VI = DSQRT(VX*VX + VY*VY)                                         SKD00960
      WD = 0.0D0                                                        SKD00970
      VYVI = VY/VI                                                      SKD00980
      IF(VYVI.LT.1.0D0)  WD = DARCOS(VYVI) * RADDEG                     SKD00990
      WRITE(6,4) ZIND,VALUE,VI,WD,AK1SQ,AK2SQ                           SKD01000
      AK1SQ = AK2SQ                                                     SKD01010
  160 CONTINUE                                                          SKD01020
C                                                                       SKD01030
      WRITE(6,5)                                                        SKD01040
      TTOT = VALUE(1)
      XTOT = VALUE(2)
      YTOT = VALUE(3)
      L = -1                                                            SKD01050
      RETURN                                                            SKD01060
C                                                                       SKD01070
  180 CONTINUE                                                          SKD01080
      CALL INTERP(AK1SQ,AK2SQ,ZI(I-1),ZI(I),AKX,AKY,VALUE)             SKD01090
C                                                                       SKD01100
      TTOT = T2                                                         SKD01110
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      XTOT = X2                                                         SKD01120
      YTOT = Y2                                                         SKD01130
      L=1                                                               SKD01140
      CALL ARTLU(2,ZTOP,ZI,VXTOP,VXI,VYTOP,VYI)                         SKD01150
      VT= DSQRT(VXTOP*VXTOP & VYTOP*VYTOP)                              SKD01160
      WD =0.0D0                                                         SKD01170
      VYVT = VY/VT                                                      SKD01180
      IF(VYVT.LT.1.0D0) WD=DARCOS(VYVT)*RADDEG                          SKD01190
      WRITE(6,10)ZTOP,TTOP,XTOP,YTOP,VT,WD                              SKD01200
                                                                        SKD01210
    1 FORMAT(' ** Z0 = ',G15.5,2X,'ZMAX = ',G15.5)                      SKD01220
    2 FORMAT(' ** NO RAY AT ALTITUDE OF ',G15.5)                        SKD01230
    3 FORMAT('0',9X,'HEIGHT',11X,'TIME',10X,'XDIST',10X, 'YDIST',       SKD01240
     1       11X,'VT',13X,'WD', 9X,'KZ1SQ',10X,'KZ2SQ',/' ')           SKD01250
    4 FORMAT(' ',6F15.4,2G15.5)                                         SKD01260
    5 FORMAT(' ** NOT ENOUGH DATA')                                     SKD01270
    6 FORMAT(' ** DELZ = ',G15.5)                                       SKD01280
    7 FORMAT('1',12X,'RAY PARAMETERS - KX = ',F12.4,2X,'KY = ',F12.4)   SKD01290
    8 FORMAT(' ** SUB DHPCG - IHLF = ',I4)                              SKD01300
    9 FORMAT(' ** DEL Z TOO SMALL - DEL Z = ',G15.5)                    SKD01310
   10 FORMAT('0',6F15.4,2X, 'REFLECTION',/' ')                          SKD01320
      RETURN                                                            SKD01330
      END                                                               SKD01340
      IMPLICIT REAL*8 (A-H,O-Z)                                         DND00010
                                                                        DND00020
      SUBROUTINE DNDIST(NOPIN,ZS,IS,XS,YS,AKX,AKY,TTOT,XTOT,YTOT,L)     DND00030
                                                                        DND00040
      MODIFIED FOR PREDICTOR CORRECTOR                                  DND00050
                                                                        DND00060
      COMMON/FAYE/CI(300),VXI(300),VYI(300),ZI(300),PLXT(600),PLYZ(600),DND00070
     1            PLYX(600),PLYY(600)                                   DND00080
      COMMON/JANET/NMAX,NPLT                                            DND00090
      COMMON/PEARL/ZTOP,TTOP,XTOP,YTOP                                  DND00100
      DIMENSION VALUE(3),DERN(3),UPBND(3),DNBND(3)                      DND00110
      COMMON/JULIA/QAKX,QAKY                                            DND00120
                                                                        DND00140
      RADDEG = 57.29577951310D0                                         DND00150
      AKXKY = AKX*AKX & AKY*AKY                                         DND00160
      QAKX = AKX                                                        DND00170
      QAKY = AKY                                                        DND00180
                                                                        DND00190
      IF(ZS.LT.ZI(NMAX)) GO TO 110                                      DND00200
      WRITE(6,1) ZS,ZI(NMAX)                                            DND00210
      CALL EXIT                                                         DND00220
                                                                        DND00230
  110 CONTINUE                                                          DND00240
                                                                        DND00250
      DO 120 I=2,NMAX                                                   DND00260
      IF(ZS.LE.ZI(I)) GO TO 130                                         DND00270
  120 CONTINUE                                                          DND00280
                                                                        DND00290
  130 CONTINUE                                                          DND00300
      IXX = I-1                                                         DND00310
                                                                        DND00320
      CALL ARTLU(3,ZS,ZI,VX,VXI,VY,VYI,C,CI)                            DND00330
                                                                        DND00340
      TM1 = (1.0D0 - AKX*VX - AKY*VY)/C                                 DND00350
      AK1SQ = TM1*TM1 - AKXKY                                           DND00360
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C                                                                       DND00370
      IF(AK1SQ.GT.0.0D0) GO TO 140                                      DND00380
      WRITE(4,2) T1                                                     DND00390
      L= -1                                                             DND00410
      RETURN                                                            DND00420
C                                                                       DND00430
  140 CONTINUE                                                          DND00440
C                                                                       DND00450
C     INITIAL CONDITIONS                                                DND00460
C                                                                       DND00470
      NEQ = 3                                                           DND00480
      DATA UPBND/1.0D-2,2*1.0D0/                                        DND00490
      DATA DNBND/1.0D-4,2*1.0D-2/                                       DND00500
      FACTOR = .5D0                                                     DND00510
      ZIND = ZS                                                         DND00520
      DELMIT = 0.0D0                                                    DND00530
      VALUE(1) = TS                                                     DND00540
      VALUE(2) = XS                                                     DND00550
      VALUE(3) = YS                                                     DND00560
      T1 = TS                                                           DND00570
      X1 = XS                                                           DND00580
      Y1 = YS                                                           DND00590
      JZ = IXX + 1                                                      DND00600
      WRITE(6,5) ZIND,VALUE                                             DND00610
C                                                                       DND00620
      DO  160 I = 1,IXX                                                 DND00630
      JZ = JZ - 1                                                       DND00640
      HLIMIT = ZI(JZ)                                                   DND00650
      DEL =      (HLIMIT-ZIND)*1.0D-1                                   DND00660
      FREQ = 10.0D0*DEL                                                 DND00670
      LQX = 1                                                           DND00680
      IF(HLIMIT.GT.ZI(1)) GO TO 145                                     DND00690
      VX = VXI(1)                                                       DND00700
      VY = VYI(1)                                                       DND00710
      C = CI(1)                                                         DND00720
      GO TO 146                                                         DND00730
  145 CONTINUE                                                          DND00740
      CALL ARILU(3,HLIMIT,ZI,VX,VXI,VY,VYI,C,CI)                        DND00750
  146 CONTINUE                                                          DND00760
      TM1 = (1.0D0 - AKX*VX - AKY*VY)/C                                 DND00770
      AK2SQ = TM1*TM1 - AKXKY                                           DND00780
      IF(AK2SQ.LE.0.0D0) GO TO 180                                      DND00790
C                                                                       DND00800
  155 CALL ADM4RK(NEQ,DEL,VALUE,DERN,UPBND,DNBND,FACTOR,FREQ,HLIMIT,    DND00810
     1            LQX,ZIND,DELMIT)                                      DND00820
      GO TO(155,155,157,157,155,156),LQX                                DND00830
C                                                                       DND00840
  156 WRITE(6,4)                                                        DND00850
      L = -1                                                            DND00860
      RETURN                                                            DND00870
C                                                                       DND00880
  157 CONTINUE                                                          DND00890
      NPLT = NPLT + 1                                                   DND00900
      T1 = T1 + (T1 - VALUE(1))                                         DND00910
      X1 = X1 + (X1 - VALUE(2))                                         DND00920
      Y1 = Y1 + (Y1 - VALUE(3))                                         DND00930
      VALUE(1) = T1                                                     DND00940
      VALUE(2) = X1                                                     DND00950
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      VALUE(3) = Y1                                                     DND00960
      PLXT(NPLT) = VALUE(1)                                             DND00970
      PLYX(NPLT) = VALUE(2)                                             DND00980
      PLYY(NPLT) = VALUE(3)                                             DND00990
      PLYZ(NPLT) = ZIND                                                 DND01000
      IF(ZIND.GT.ZI(1)) GO TO 159                                       DND01010
      VX = VXI(1)                                                       DND01020
      VY = VYI(1)                                                       DND01030
      GO TO 159                                                         DND01040
  158 CONTINUE                                                          DND01050
      CALL ARTLU(2,ZIND,ZI,VX,VXI,VY,VYI)                               DND01060
  159 CONTINUE                                                          DND01070
      VT = DSQRT(VX*VX + VY*VY)                                         DND01080
      WD = 0.0D0                                                        DND01090
      VYVT = VY/VT                                                      DND01100
      IF(VYVT.LT.1.0D0) WD = DARCOS(VYVT) * RADDEG                      DND01110
      WRITE(6,5) ZIND,VALUE,VT,WD,AK1SQ,AK2SQ                           DND01120
      AK1SQ = AK2SQ                                                     DND01130
  160 CONTINUE                                                          DND01140
                                                                        DND01150
      TTOT = VALUE(1)                                                   DND01160
      XTOT = VALUE(2)                                                   DND01170
      YTOT = VALUE(3)                                                   DND01180
      L = 1                                                             DND01190
      RETURN                                                            DND01200
                                                                        DND01210
  180 WRITE(6,6) AK2SQ,HLIMIT                                           DND01220
    1 FORMAT(' ** ZO = ',G15.5,2X,'ZMAX = ',G15.5)                      DND01240
    2 FORMAT(' ** NO RAY AT ALTITUDE OF ',G15.5)                        DND01250
    4 FORMAT(' ** DEL Z TOO SMALL')                                     DND01260
    5 FORMAT(' ',6E15.4,2G15.5)                                         DND01270
    6 FORMAT(' ** K2SQ NEGATIVE - K2SQ = ',G15.5,' Z = ',G15.5)         DND01280
      RETURN                                                            DND28880
      END                                                               DND28890
      IMPLICIT REAL*8 (A-H,O-Z)                                         INT00010
                                                                        INT00020
      SUBROUTINE INTERP(AK1SQ,AK2SQ,Z1,Z2,AKX,AKY,VALUE)                INT00030
                                                                        INT00040
      COMMON/FAYE/CI(300),VXI(300),VYI(300),ZI(300),PLXT(600),PLYZ(600),INT00050
     1            PLYX(600),PLYY(600)                                   INT00060
      COMMON/JANET/NMAX,NPLT                                            INT00070
      COMMON/PEARL/ZTOP,TTOP,XTOP,YTOP,T2,X2,Y2                         INT00080
      DIMENSION VALUE(1)                                                INT00090
                                                                        INT00100
      T1 = VALUE(1)                                                     INT00110
      X1 = VALUE(2)                                                     INT00120
      Y1 = VALUE(3)                                                     INT00130
      CALL ARTLU(3,Z1,ZI,C,CI,VX,VXI,VY,VYI)                            INT00140
      CALL PARAM(AKX,AKY,C,VX,VY,TUP1,XUP1,YUP1,AK1SQ)                  INT00150
      CALL ARTLU(3,Z2,ZI,C,CI,VX,VXI,VY,VYI)                            INT00160
      CALL PARAM(AKX,AKY,C,VX,VY,TUP2,XUP2,YUP2,AK2SQ)                  INT00170
      PLUS = -1.0D0                                                     INT00180
      DSIG = TUP1*(Z2-Z1)                                               INT00190
      IF(DSIG.GT.0.0D0) PLUS = 1.0D0                                    INT00200
      AK1 = PLUS*  SQRT(AK1SQ)                                          INT00210
      DENOM = AK1SQ-AK2SQ                                               INT00220
      ENUM = AK2SQ & AK1SQ/3.0D0                                        INT00230
      RAT = ENUM/DENOM                                                  INT00240
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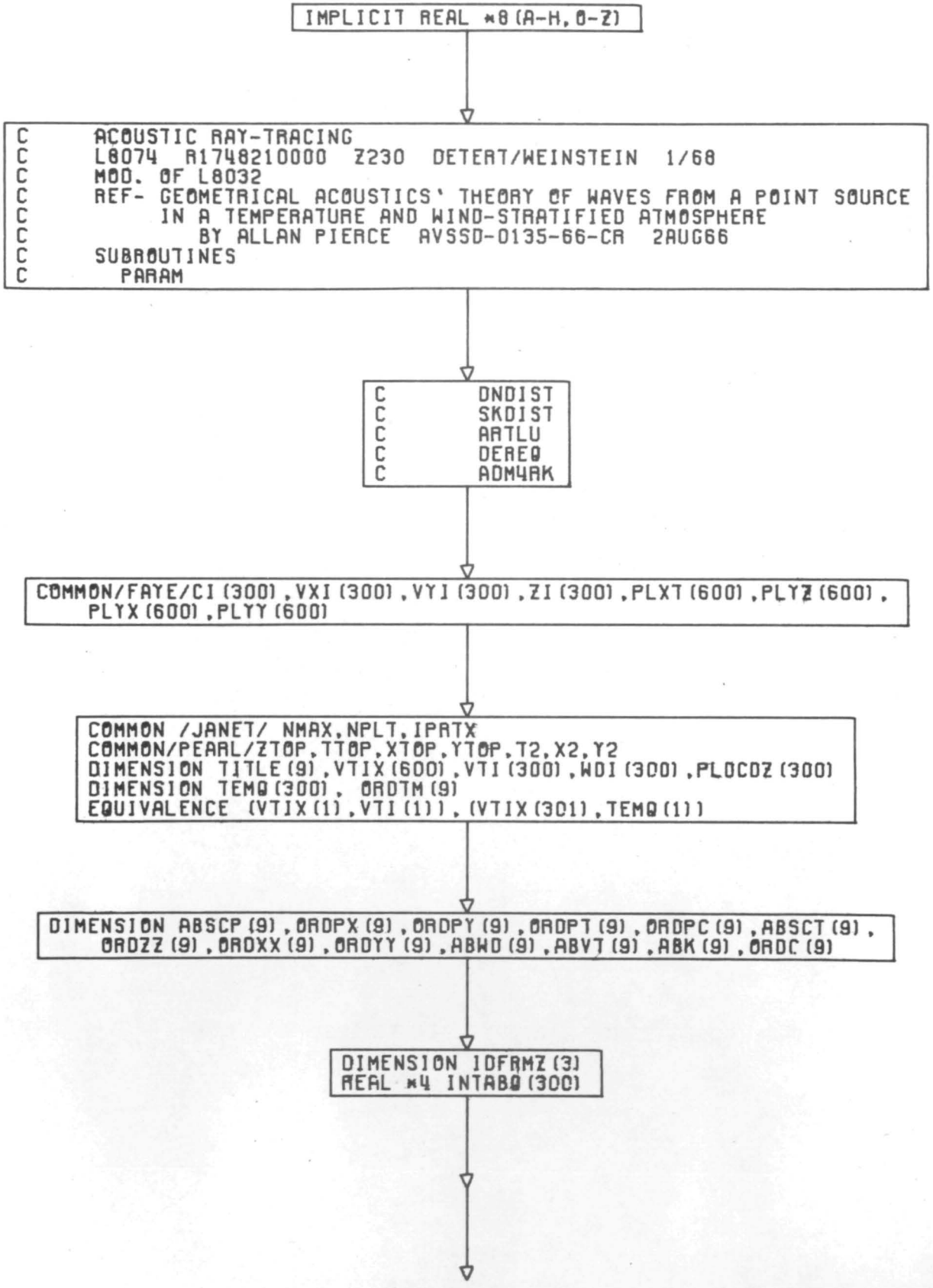
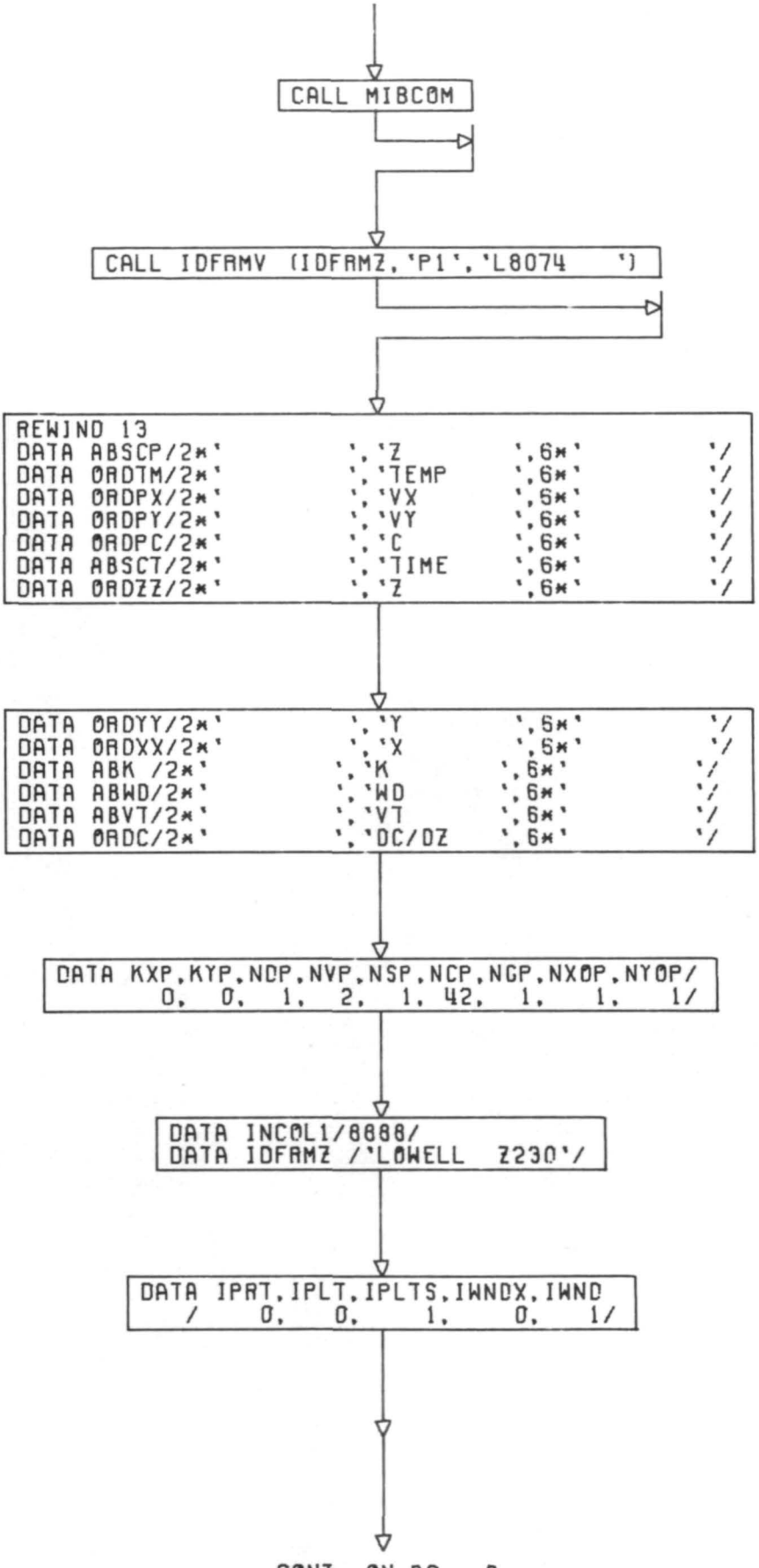
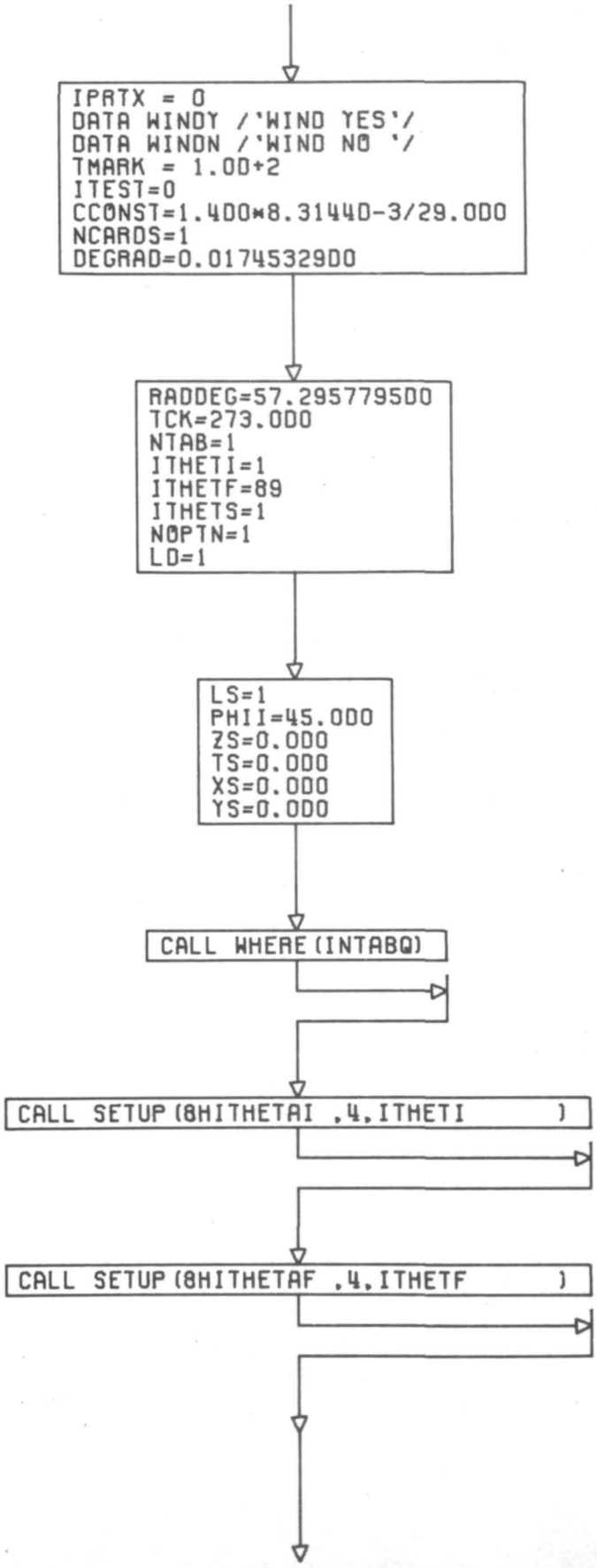
```
      TUPAV = 0.5D0*(TUP1 & TUP2) - .5D0*(TUP1-TUP2)*RAT                INT0025
      XUPAV = 0.5D0*(XUP1 & XUP2) - .5D0*(XUP1-XUP2)*RAT                INT0026
      YUPAV = 0.5D0*(YUP1 & YUP2) - .5D0*(YUP1-YUP2)*RAT                INT0027
      EQU = 4.CD0*AK1*(Z2-Z1)/DENOM                                     INT0028
      ZTOP = Z1 & (AK1SQ*(Z2-Z1)/DENOM)                                 INT0029
      TTOP= T1 & .5D0*EQU*TUPAV                                         INT0030
      XTOP= X1 & .5D0*EQU*XUPAV                                         INT0031
      YTOP= Y1 & .5D0*EQU*YUPAV                                         INT0032
      T2 = T1 & EQU*TUPAV                                               INT0033
      X2 = X1 & EQU*XUPAV                                               INT0034
      Y2 = Y1 & EQU*YUPAV                                               INT0035
      IF(T2-T1) 110,120,120                                             INT0036
  110 WRITE(6,1) TUP1,TUPAV                                             INT0037
    1 FORMAT(' ** TIME REVERSAL IN INTERP',6X,'TUP1 = ',F12.4,3X,'TUPAV'INT0038
     1,F12.4)                                                           INT0039
      T2=T1 & DABS(EQU*TUPAV)                                           INT0040
  120 CONTINUE                                                          INT0041
      RETURN                                                            INT0042
      END                                                               INT0043
      IMPLICIT REAL*8 (A-H,O-Z)                                         DER0001
C                                                                       DER0002
      SUBROUTINE DEREQ(VALUE,ZIND,DERY,LQX)                             DER0003
C                                                                       DER0004
      DIMENSION VALUE(1),DERY(1)                                        DER0005
      COMMON/JULIA/AKX,AKY                                              DER0006
      COMMON/FAYE/CI(300),VXI(300),VYI(300),ZI(300),PLXT(600),PLYZ(600),DER0007
     1            PLYX(600),PLYY(600)                                   DER0008
      IF(ZIND.GT.ZI(1)) GO TO 100                                       DER0009
      VX = VXI(1)                                                       DER0010
      VY = VYI(1)                                                       DER0011
      C = CI(1)                                                         DER0012
      GO TO 110                                                         DER0013
  100 CONTINUE                                                          DER0014
      CALL ARTLU(3,ZIND,ZI,VX,VXI,VY,VYI,C,CI)                          DER0015
  110 CONTINUE                                                          DER0016
      OMEGA = 1.0D0 - AKX*VX - AKY*VY                                   DER0017
      TUP = OMEGA/C**2                                                  DER0018
      XUP = AKX & VX*TUP                                                DER0019
      YUP = AKY & VY*TUP                                                DER0020
      AKZSQ= OMEGA* TUP - AKX*AKX - AKY*AKY                             DER0021
        AKZ = DSQRT(AKZSQ)                                              DER0022
      DERY(1) = TUP/AKZ                                                 DER0023
      DERY(2) = XUP/AKZ                                                 DER0024
      DERY(3) = YUP/AKZ                                                 DER0025
      RETURN                                                            DER0026
      END                                                               DER0027
```

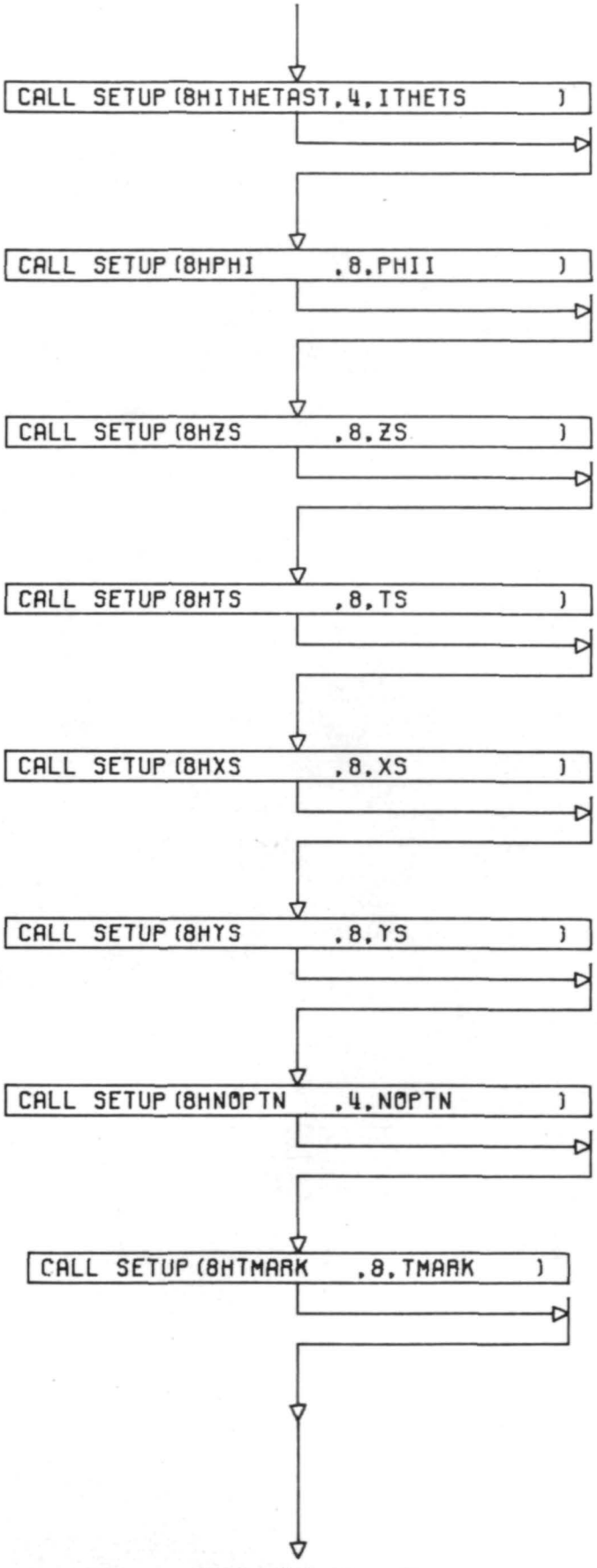
FLOW CHARTS OF ACOUSTIC RAY-TRACING COMPUTER PROGRAM


IMPLICIT REAL *8(A-H,O-Z)
C ACOUSTIC RAY-TRACING
C L8074 R1748210000 Z230 DETERT/WEINSTEIN 1/68
C MOD. OF L8032
C REF- GEOMETRICAL ACOUSTICS' THEORY OF WAVES FROM A POINT SOURCE
C IN A TEMPERATURE AND WIND-STRATIFIED ATMOSPHERE
C BY ALLAN PIERCE AVSSD-0135-66-CR 2AUG66
C SUBROUTINES
C PARAM
C DNDIST
C SKDIST
C ARTLU
C DEREQ
C ADMARK
COMMON/FAYE/CI(300),VXI(300),VYI(300),ZI(300),PLXT(600),PLYZ(600),
PLYX(600),PLYY(600)
COMMON /JANET/ NMAX,NPLT,IPRTX
COMMON/PEARL/ZTOP,TTOP,XTOP,YTOP,T2,X2,Y2
DIMENSION TITLE(9),VTIX(600),VTI(300),WDI(300),PLOCOZ(300)
DIMENSION TEMQ(300), ORDTM(9)
EQUIVALENCE (VTIX(1),VTI(1)),(VTIX(301),TEMQ(1))
DIMENSION ABSCP(9),ORDPX(9),ORDPY(9),ORDPT(9),ORDPC(9),ABSCT(9),
ORDZZ(9),ORDXX(9),ORDYY(9),ABWD(9),ABVT(9),ABK(9),ORDC(9)
DIMENSION IDFRMZ(3)
REAL *4 INTABQ(300)
CONT. ON PG 2

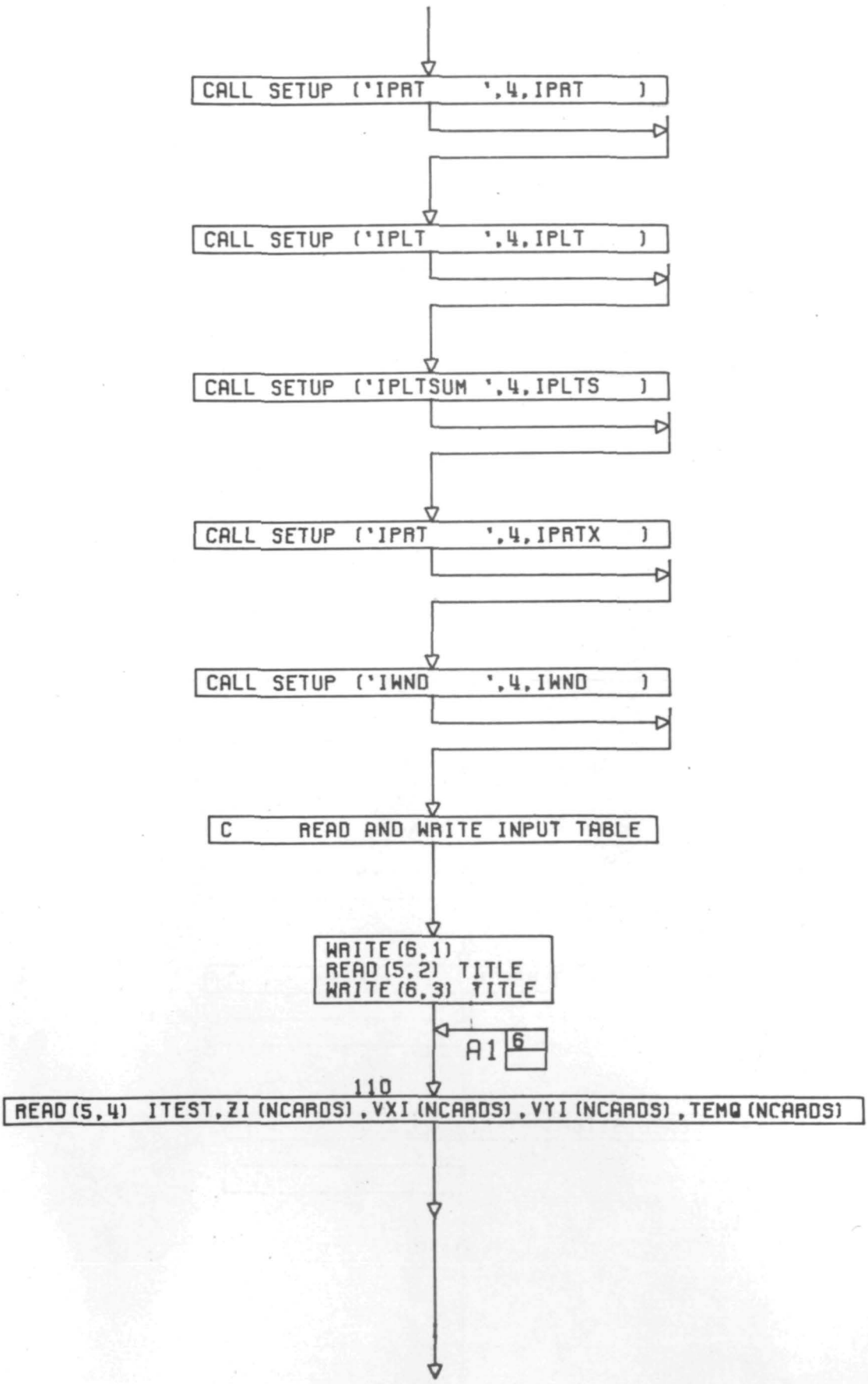

CALL MIBCOM
CALL IDFRMV (IDFRMZ,'P1','L8074 ')
REWIND 13
DATA ABSCP/2*' ','Z ',6*' '/
DATA ORDTM/2*' ','TEMP ',6*' '/
DATA ORDPX/2*' ','VX ',5*' '/
DATA ORDPY/2*' ','VY ',6*' '/
DATA ORDPC/2*' ','C ',6*' '/
DATA ABSCT/2*' ','TIME ',6*' '/
DATA ORDZZ/2*' ','Z ',6*' '/
DATA ORDYY/2*' ','Y ',6*' '/
DATA ORDXX/2*' ','X ',6*' '/
DATA ABK /2*' ','K ',6*' '/
DATA ABWD/2*' ','WD ',6*' '/
DATA ABVT/2*' ','VT ',6*' '/
DATA ORDC/2*' ','DC/DZ ',6*' '/
DATA KXP,KYP,NDP,NVP,NSP,NCP,NGP,NXOP,NYOP/
0, 0, 1, 2, 1, 42, 1, 1, 1/
DATA INCOL1/8888/
DATA IDFRMZ /'LOWELL Z230'/
DATA IPRT,IPLT,IPLTS,IWNDX,IWND
/ 0, 0, 1, 0, 1/

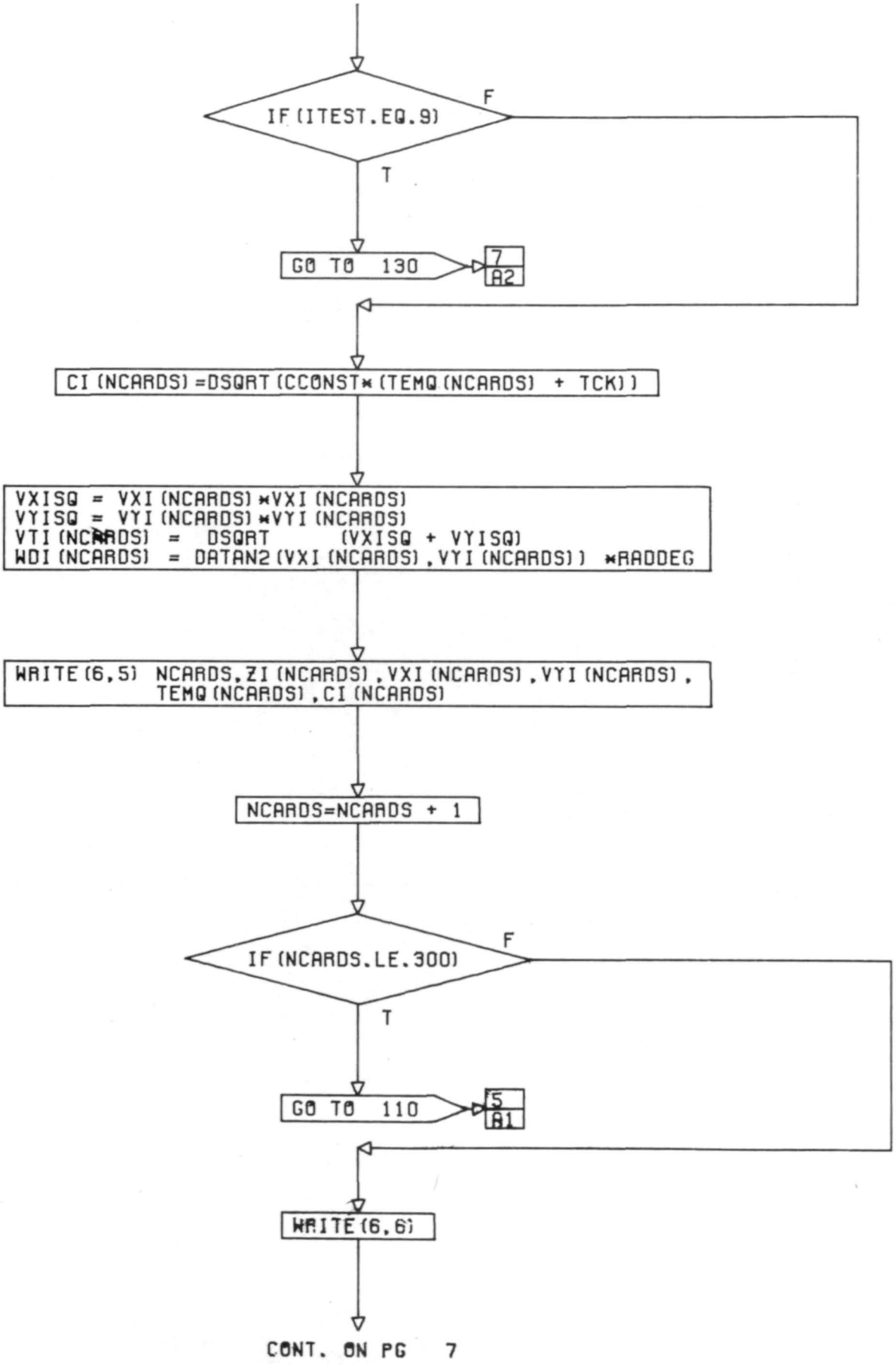
CONT. ON PG 3

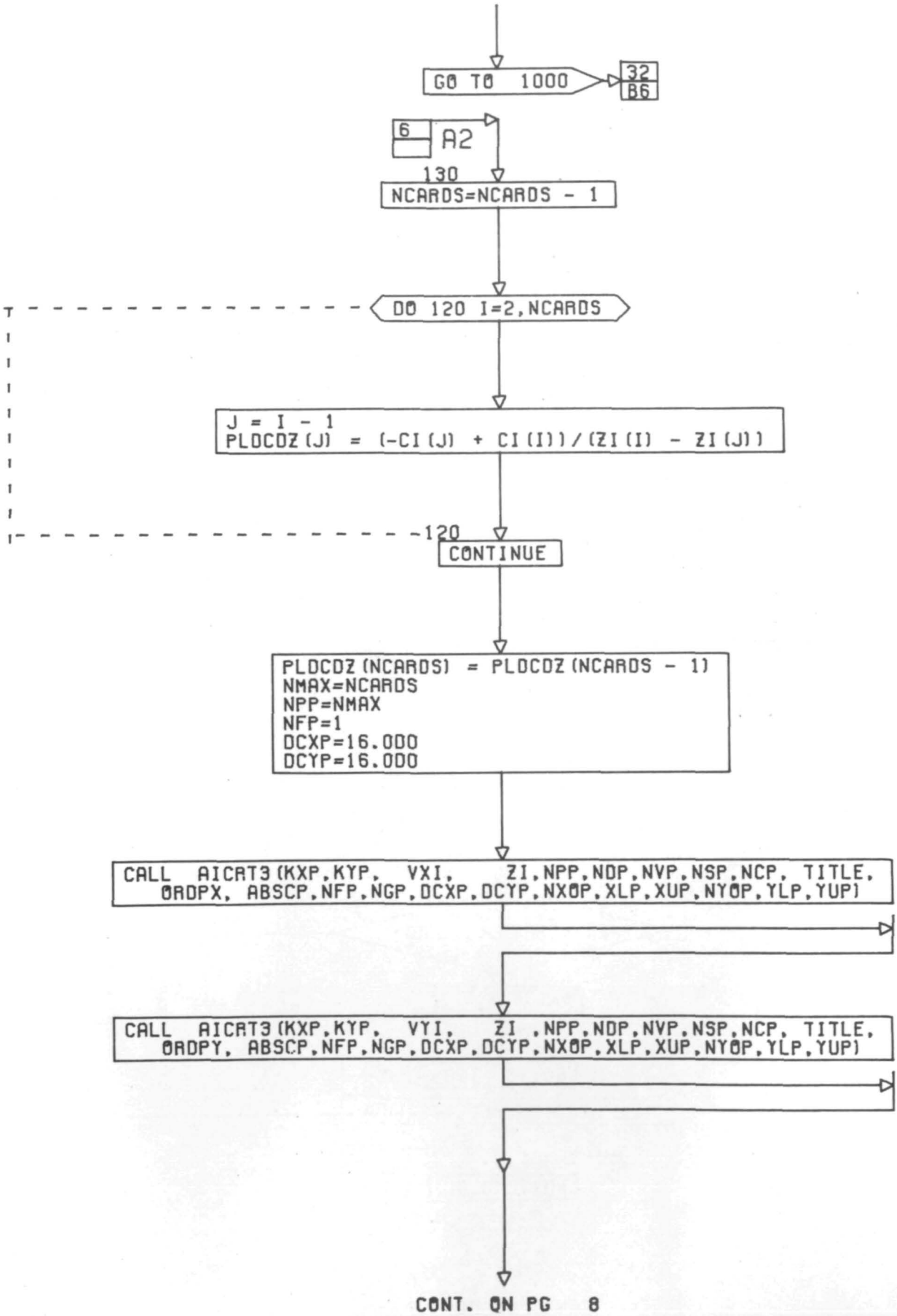

IPRTX = 0
DATA WINDY /'WIND YES'/
DATA WINDN /'WIND NO '/
TMARK = 1.0D+2
ITEST=0
CCONST=1.4D0*8.3144D-3/29.0D0
NCARDS=1
DEGRAD=0.0174532900
RADDEG=57.2957795D0
TCK=273.0D0
NTAB=1
ITHETI=1
ITHETF=89
ITHETS=1
NOPTN=1
LD=1
LS=1
PHII=45.0D0
ZS=0.0D0
TS=0.0D0
XS=0.0D0
YS=0.0D0
CALL WHERE(INTABQ)
CALL SETUP(8HITHETAI ,4,ITHETI)
CALL SETUP(8HITHETAF ,4,ITHETF)
CONT. ON PG 4

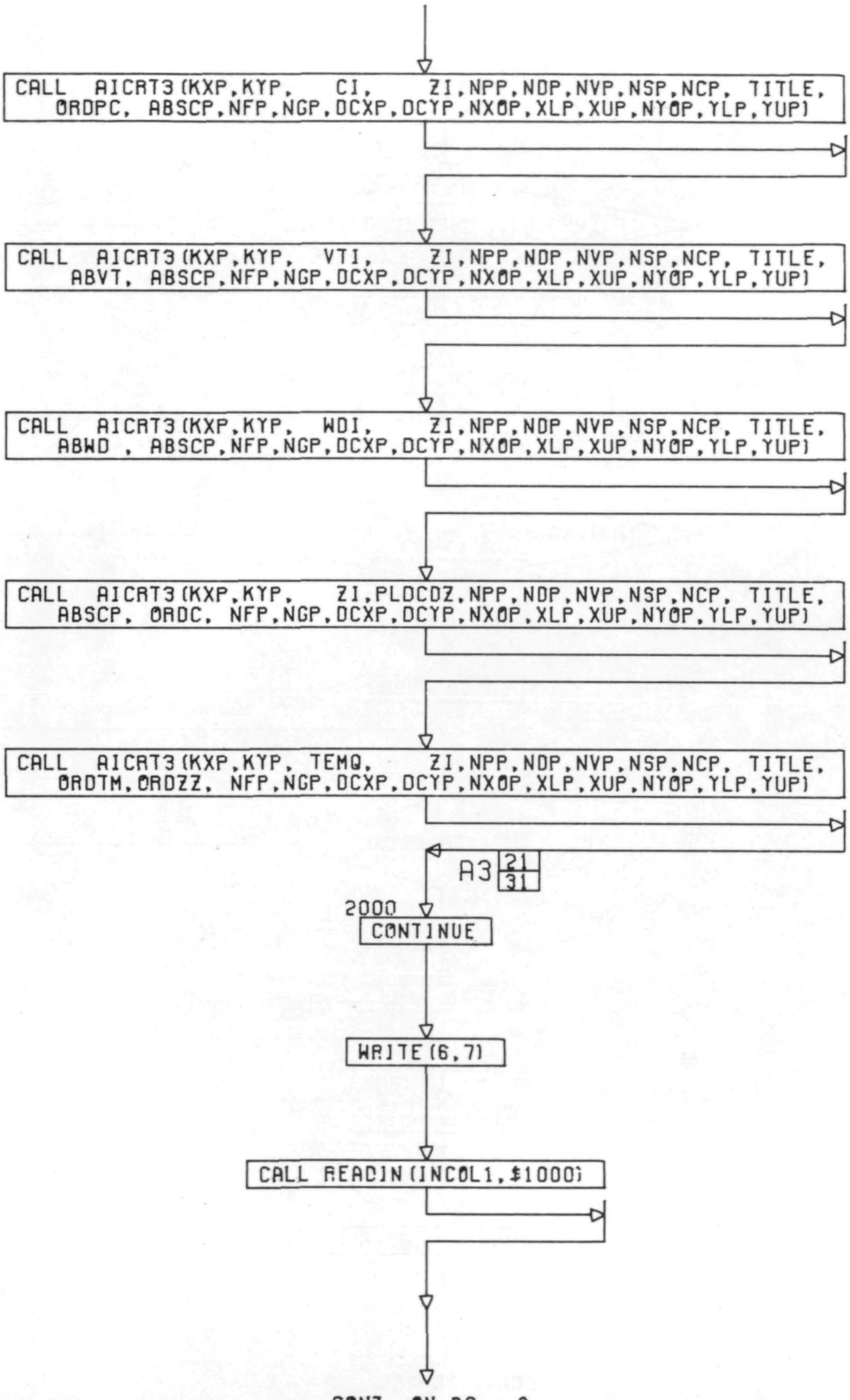

CALL SETUP(8HITHETAST,4,ITHETS)
CALL SETUP(8HPHI ,8,PHII)
CALL SETUP(8HZS ,8,ZS)
CALL SETUP(8HTS ,8,TS)
CALL SETUP(8HXS ,8,XS)
CALL SETUP(8HYS ,8,YS)
CALL SETUP(8HNOPTN ,4,NOPTN)
CALL SETUP(8HTMARK ,8,TMARK)

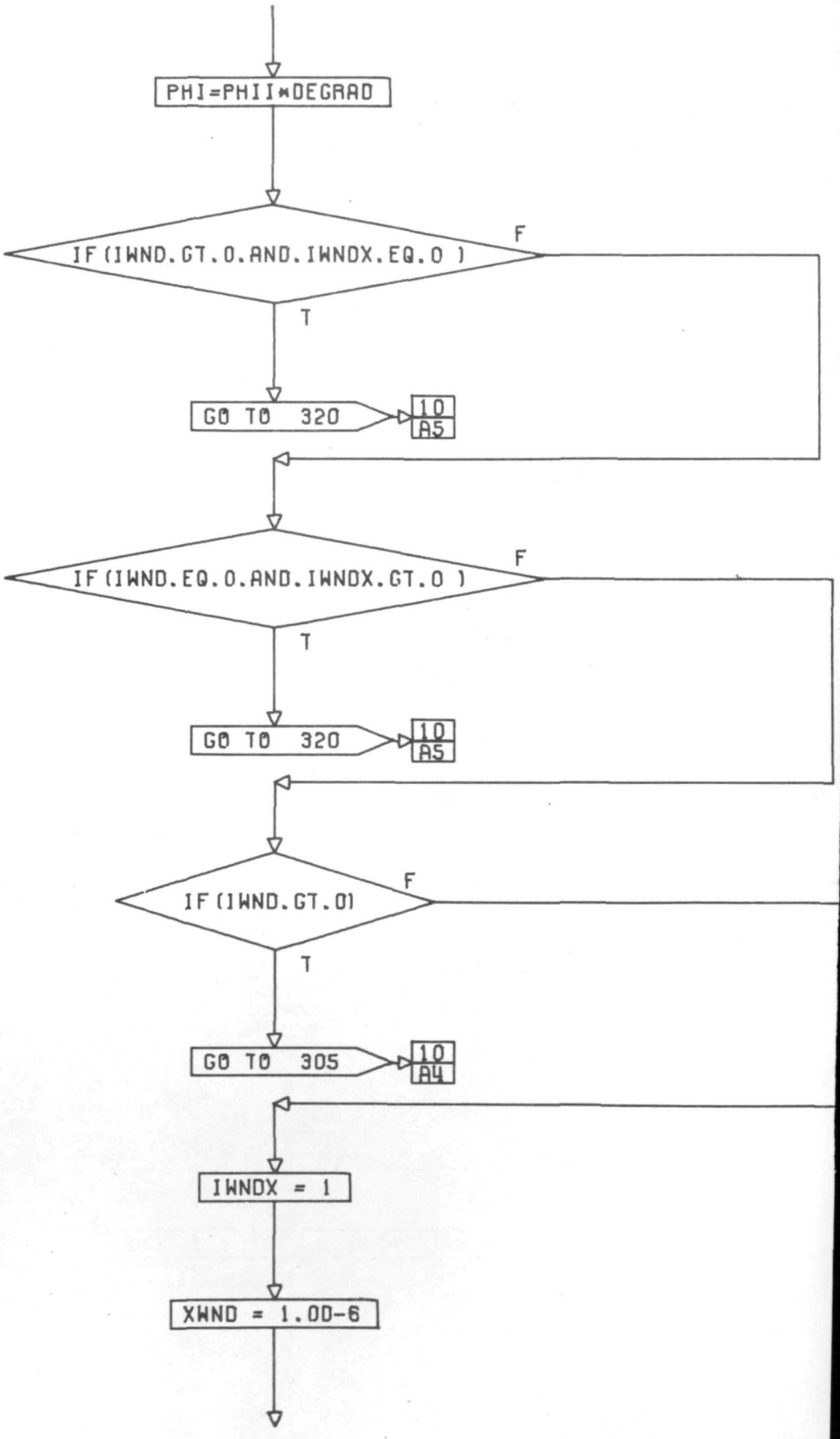
CONT. ON PG 5


CALL SETUP ('IPRT ',4,IPRT)
CALL SETUP ('IPLT ',4,IPLT)
CALL SETUP ('IPLTSUM ',4,IPLTS)
CALL SETUP ('IPRT ',4,IPRTX)
CALL SETUP ('IWND ',4,IWND)
C READ AND WRITE INPUT TABLE
WRITE(6,1)
READ(5,2) TITLE
WRITE(6,3) TITLE
A1
6
110
READ(5,4) ITEST,ZI(NCARDS),VXI(NCARDS),VYI(NCARDS),TEMQ(NCARDS)
CONT. ON PG 6

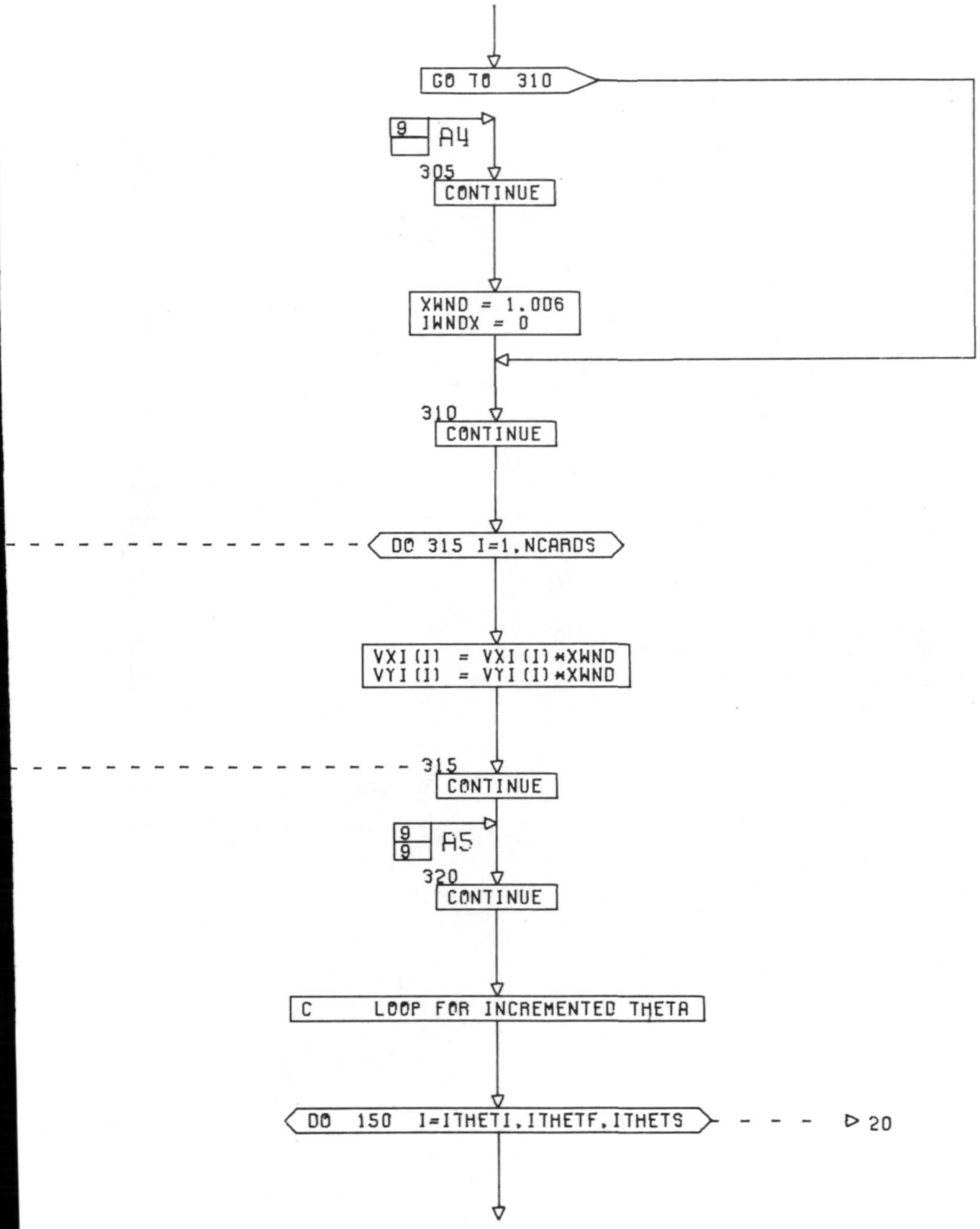

IF (ITEST.EQ.9)
F
T
GO TO 130
7
A2
CI (NCARDS) =DSQRT (CCONST* (TEMQ (NCARDS) + TCK))
VXISQ = VXI (NCARDS) *VXI (NCARDS)
VYISQ = VYI (NCARDS) *VYI (NCARDS)
VTI (NCARDS) = DSQRT (VXISQ + VYISQ)
WDI (NCARDS) = DATAN2 (VXI (NCARDS) , VYI (NCARDS)) *RADDEG
WRITE (6,5) NCARDS, ZI (NCARDS) , VXI (NCARDS) , VYI (NCARDS) ,
TEMQ (NCARDS) , CI (NCARDS)
NCARDS=NCARDS + 1
IF (NCARDS.LE.300)
F
T
GO TO 110
5
A1
WRITE (6,6)
CONT. ON PG 7


GO TO 1000
32
B6
6
A2
130
NCARDS=NCARDS - 1
DO 120 I=2,NCARDS
J = I - 1
PLOCDZ(J) = (-CI(J) + CI(I))/(ZI(I) - ZI(J))
120
CONTINUE
PLOCDZ(NCARDS) = PLOCDZ(NCARDS - 1)
NMAX=NCARDS
NPP=NMAX
NFP=1
DCXP=16.000
DCYP=16.000
CALL AICRT3(KXP,KYP, VXI, ZI,NPP,NDP,NVP,NSP,NCP, TITLE,
ORDPX, ABSCP,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CALL AICRT3(KXP,KYP, VYI, ZI ,NPP,NDP,NVP,NSP,NCP, TITLE,
ORDPY, ABSCP,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CONT. ON PG 8

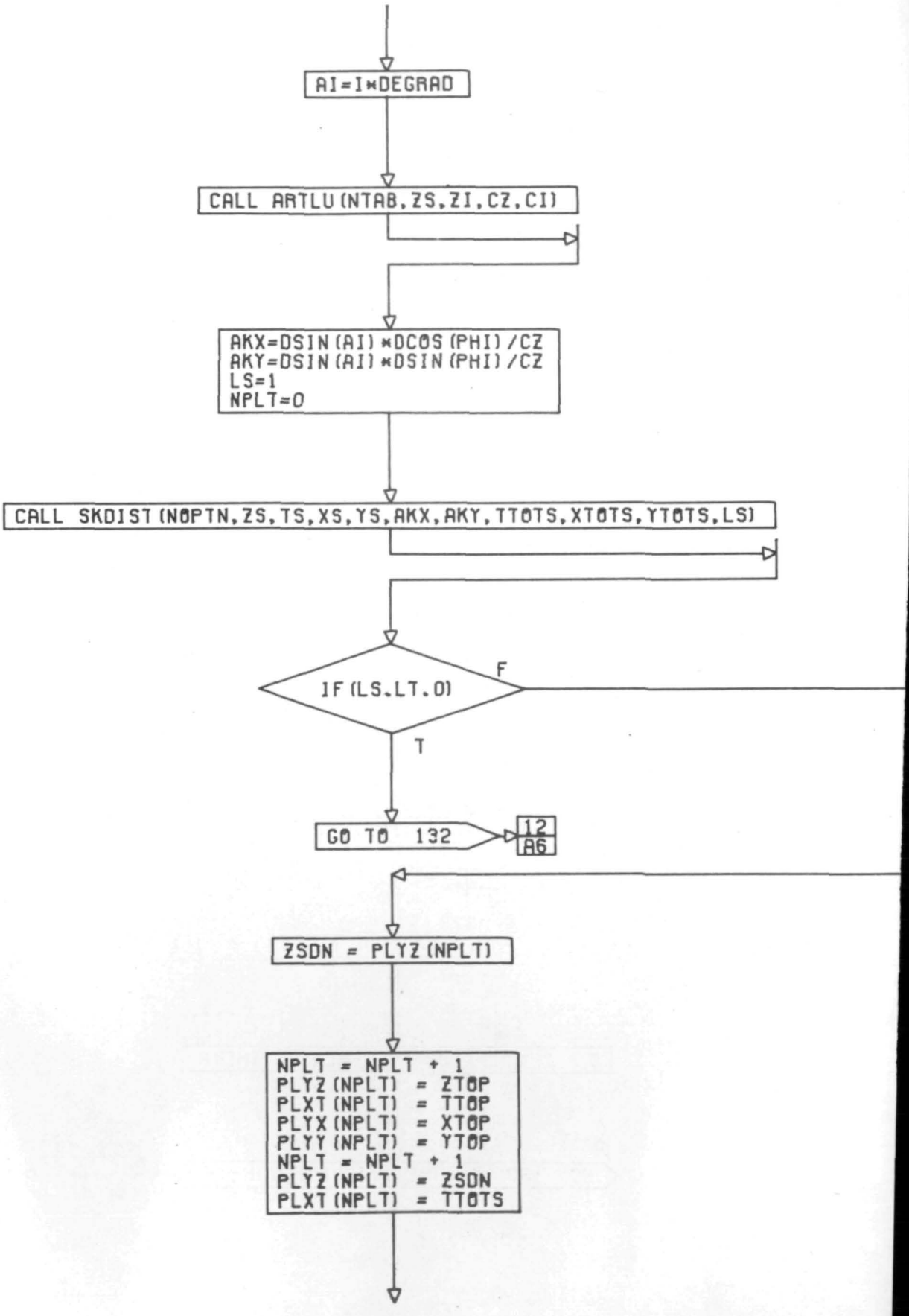

CALL AICRT3(KXP,KYP, CI, ZI,NPP,NDP,NVP,NSP,NCP, TITLE,
ORDPC, ABSCP,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CALL AICRT3(KXP,KYP, VTI, ZI,NPP,NDP,NVP,NSP,NCP, TITLE,
ABVT, ABSCP,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CALL AICRT3(KXP,KYP, WDI, ZI,NPP,NDP,NVP,NSP,NCP, TITLE,
ABWD , ABSCP,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CALL AICRT3(KXP,KYP, ZI,PLDCDZ,NPP,NDP,NVP,NSP,NCP, TITLE,
ABSCP, ORDC, NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CALL AICRT3(KXP,KYP, TEMQ, ZI,NPP,NDP,NVP,NSP,NCP, TITLE,
ORDTM,ORDZZ, NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
A3 21 31
2000
CONTINUE
WRITE(6,7)
CALL READIN(INCOL1,$1000)
CONT. ON PG 9


PHI=PHII*DEGRAD
IF(IWND.GT.0.AND.IWNDX.EQ.0)
F
T
GO TO 320
10
A5
IF(IWND.EQ.0.AND.IWNDX.GT.0)
F
T
GO TO 320
10
A5
IF(IWND.GT.0)
F
T
GO TO 305
10
A4
IWNDX = 1
XWND = 1.0D-6

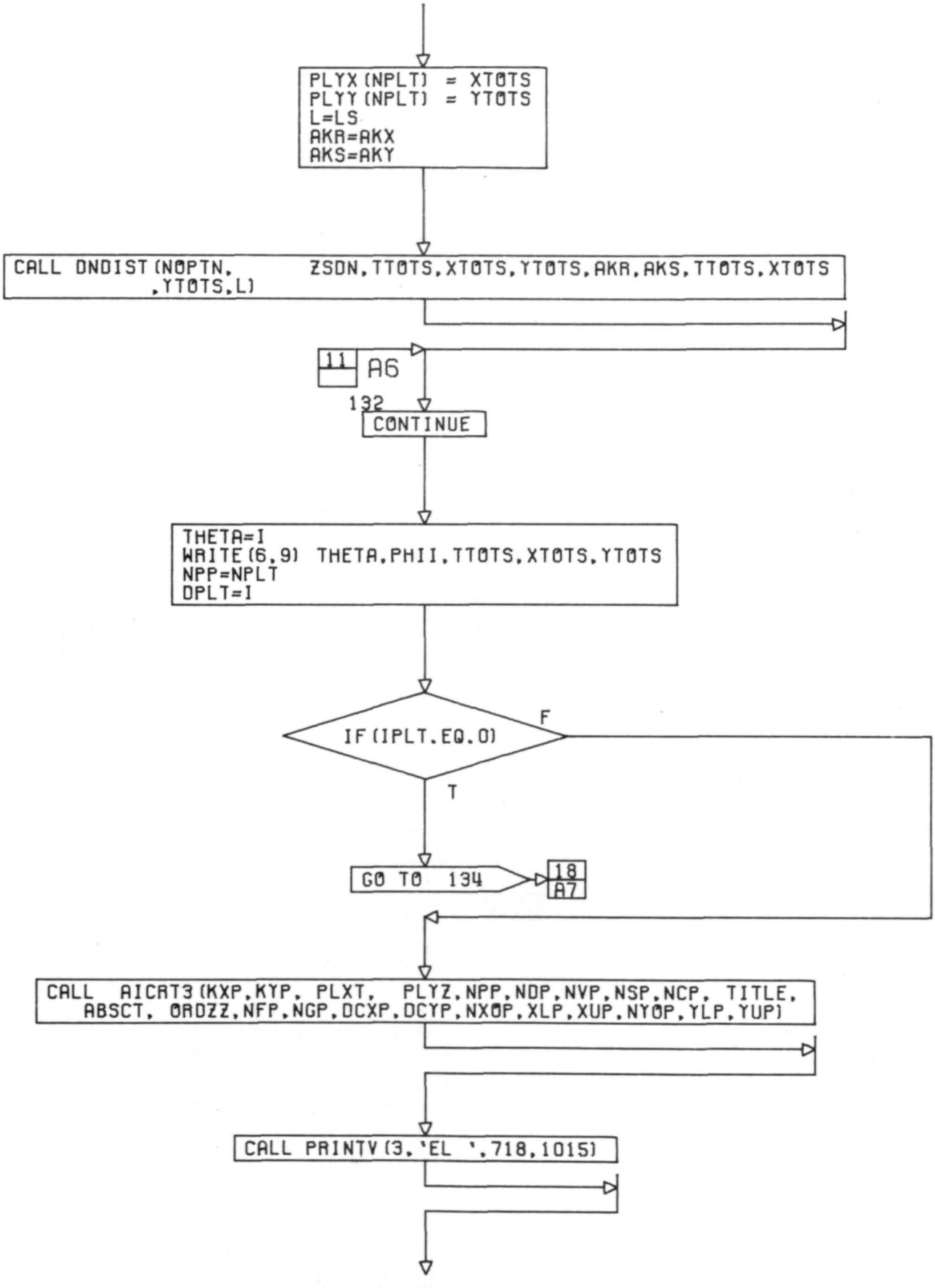
CONT. ON PG 10


GO TO 310
9
A4
305
CONTINUE
XWND = 1.006
IWNDX = 0
310
CONTINUE
DO 315 I=1,NCARDS
VXI(I) = VXI(I)*XWND
VYI(I) = VYI(I)*XWND
315
CONTINUE
9
9
A5
320
CONTINUE
C LOOP FOR INCREMENTED THETA
DO 150 I=ITHETI,ITHETF,ITHETS
▷ 20

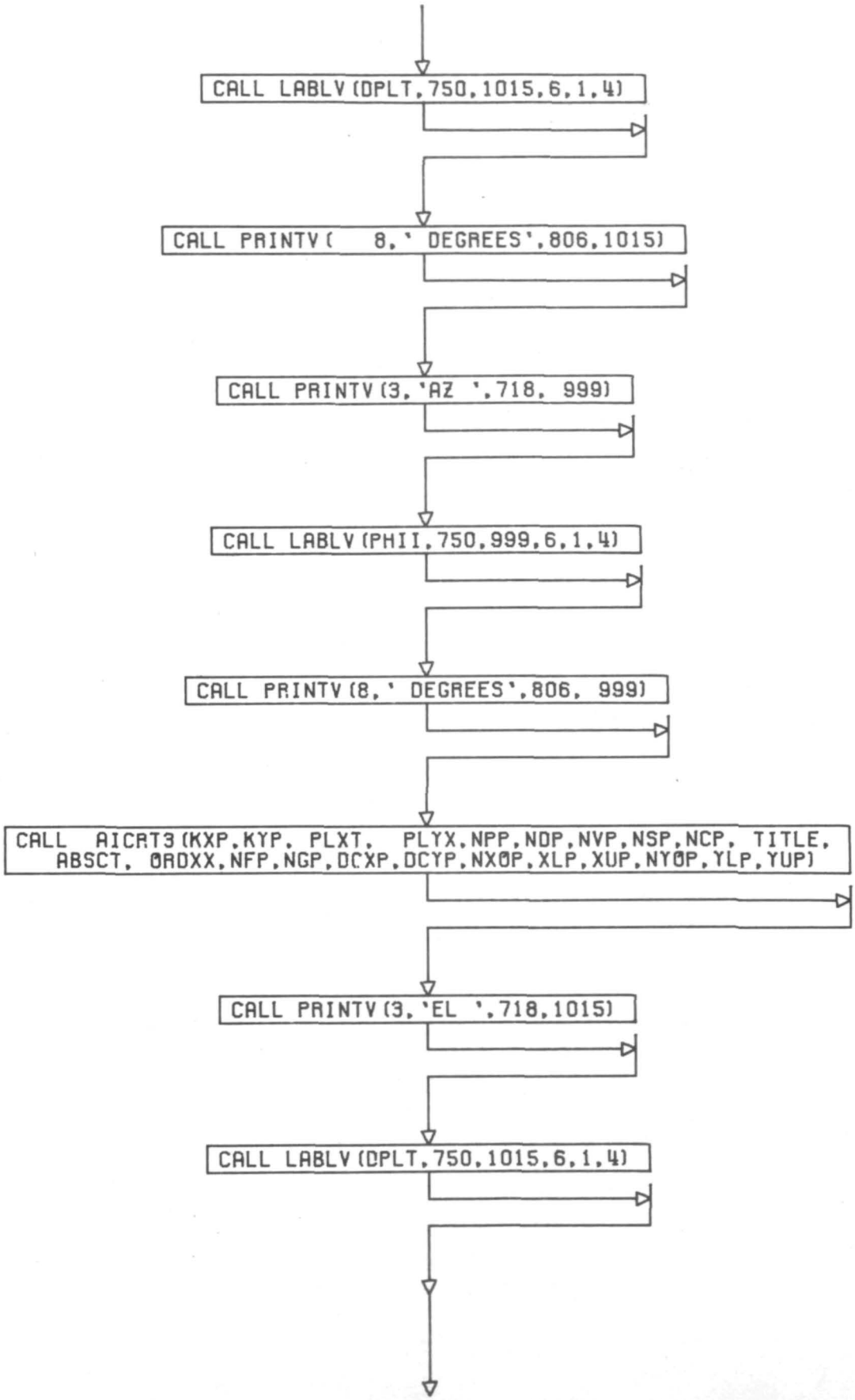
CONT. ON PG 11


AI=I*DEGRAD
CALL ARTLU(NTAB,ZS,ZI,CZ,CI)
AKX=DSIN(AI)*DCOS(PHI)/CZ
AKY=DSIN(AI)*DSIN(PHI)/CZ
LS=1
NPLT=0
CALL SKDIST(NOPTN,ZS,TS,XS,YS,AKX,AKY,TTOTS,XTOTS,YTOTS,LS)
IF(LS.LT.0)
F
T
GO TO 132
12
A6
ZSDN = PLYZ(NPLT)
NPLT = NPLT + 1
PLYZ(NPLT) = ZTOP
PLXT(NPLT) = TTOP
PLYX(NPLT) = XTOP
PLYY(NPLT) = YTOP
NPLT = NPLT + 1
PLYZ(NPLT) = ZSDN
PLXT(NPLT) = TTOTS

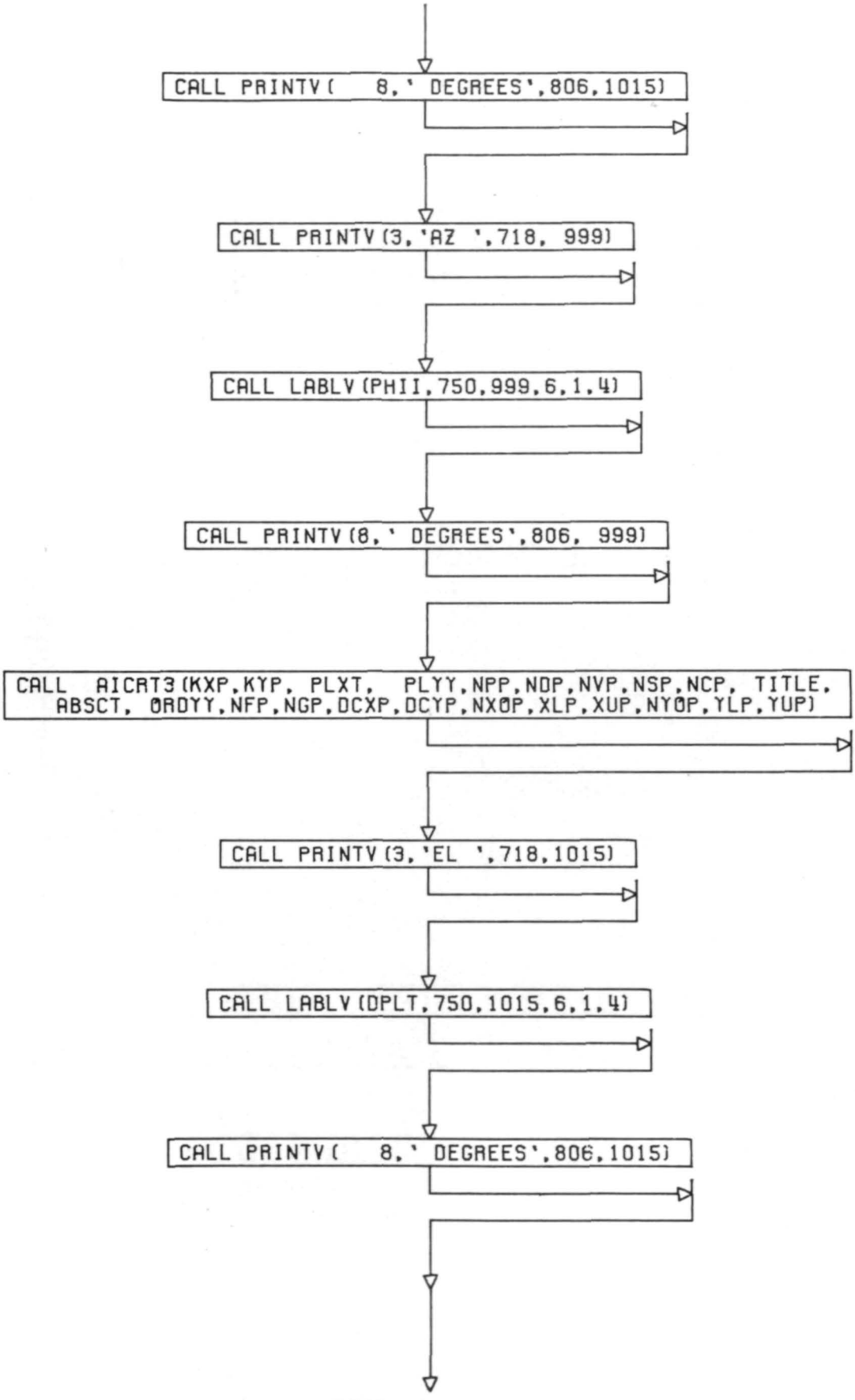
CONT. ON PG 12


PLYX(NPLT) = XTOTS
PLYY(NPLT) = YTOTS
L=LS
AKR=AKX
AKS=AKY
CALL DNDIST(NOPTN, ZSDN,TTOTS,XTOTS,YTOTS,AKR,AKS,TTOTS,XTOTS
,YTOTS,L)
11
A6
132
CONTINUE
THETA=I
WRITE(6,9) THETA,PHII,TTOTS,XTOTS,YTOTS
NPP=NPLT
DPLT=I
IF(IPLT.EQ.0)
F
T
GO TO 134
18
A7
CALL AICRT3(KXP,KYP, PLXT, PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,
ABSCT, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CALL PRINTV(3,'EL ',718,1015)

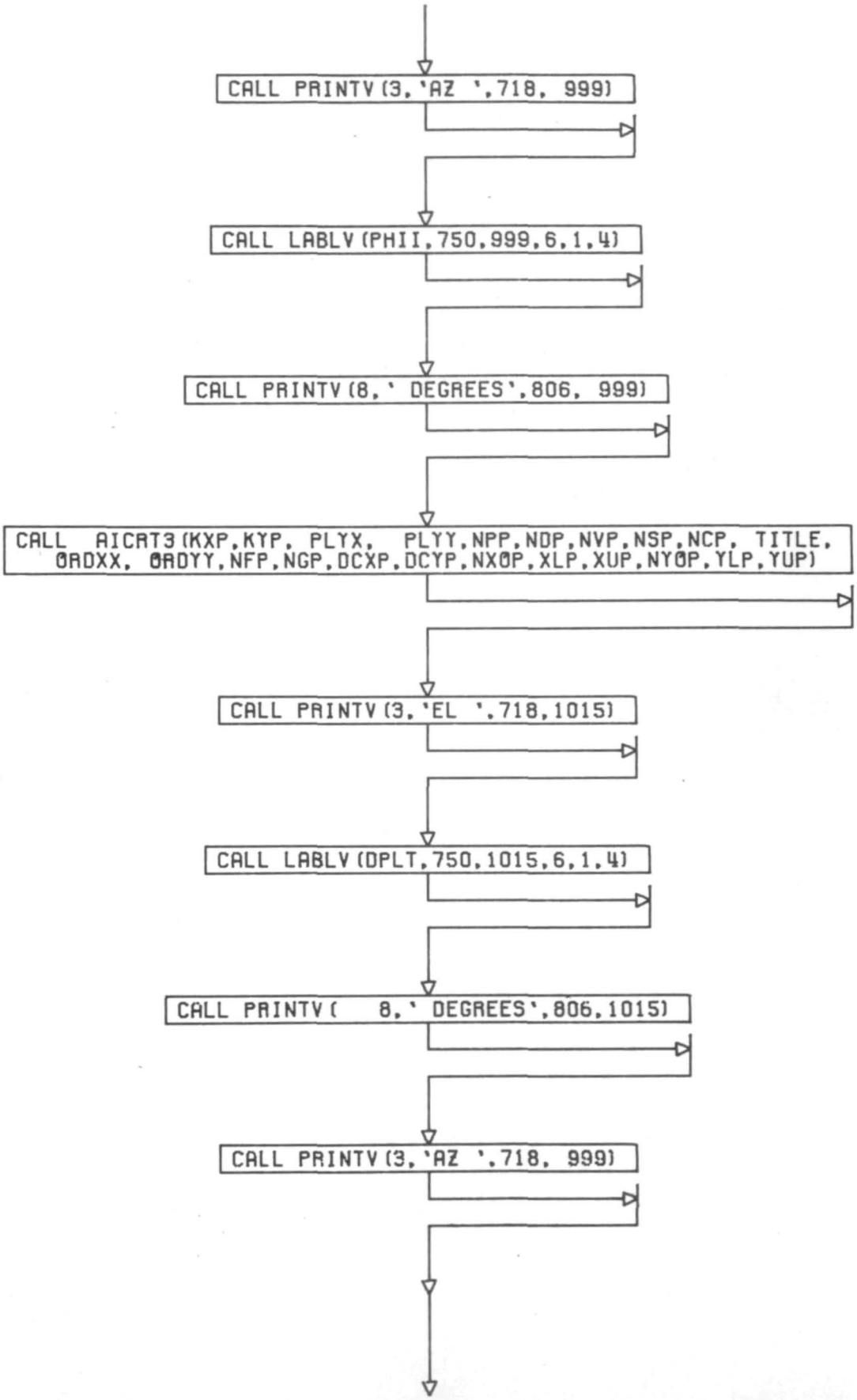
CONT. ON PG 13


CALL LABLV(DPLT,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)
CALL PRINTV(3,'AZ ',718, 999)
CALL LABLV(PHII,750,999,6,1,4)
CALL PRINTV(8,' DEGREES',806, 999)
CALL AICRT3(KXP,KYP, PLXT, PLYX,NPP,NDP,NVP,NSP,NCP, TITLE,
ABSCT, ORDXX,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CALL PRINTV(3,'EL ',718,1015)
CALL LABLV(DPLT,750,1015,6,1,4)

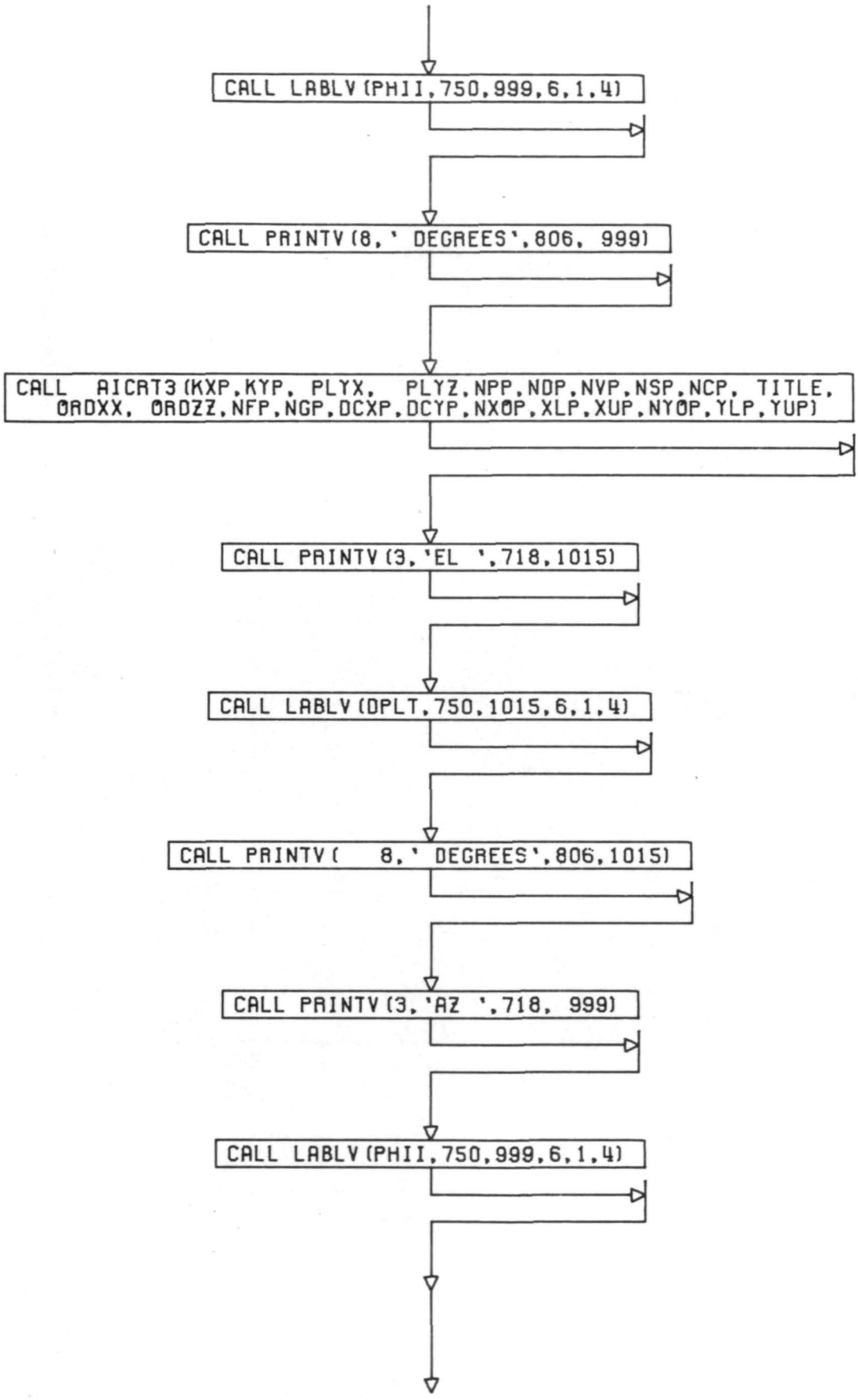
CONT. ON PG 14


CALL PRINTV(8,' DEGREES',806,1015)
CALL PRINTV(3,'AZ ',718, 999)
CALL LABLV(PHII,750,999,6,1,4)
CALL PRINTV(8,' DEGREES',806, 999)
CALL AICRT3(KXP,KYP, PLXT, PLYY,NPP,NOP,NVP,NSP,NCP, TITLE,
ABSCT, ORDYY,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CALL PRINTV(3,'EL ',718,1015)
CALL LABLV(DPLT,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)

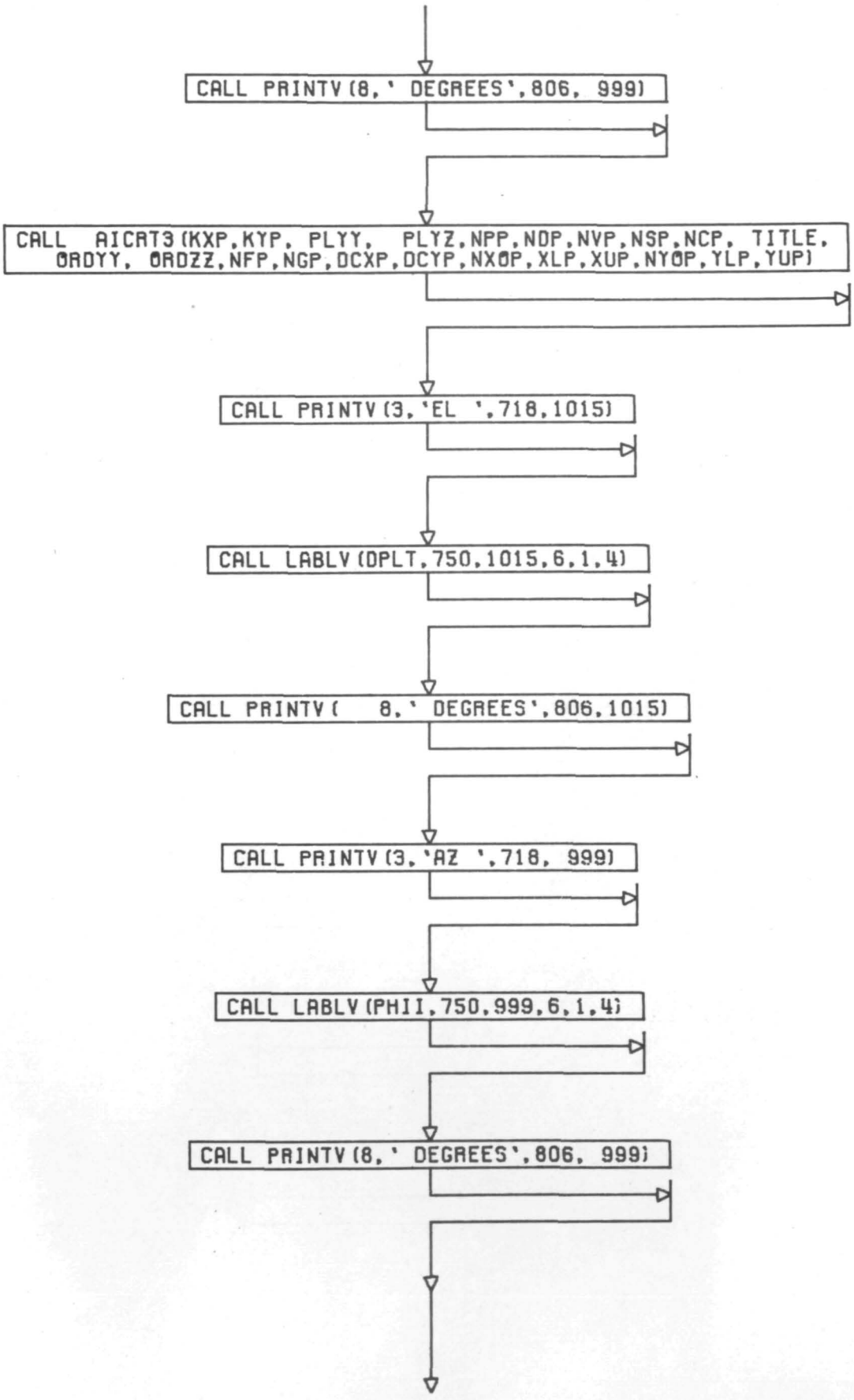
CONT. ON PG 15


CALL PRINTV(3,'AZ ',718, 999)
CALL LABLV(PHII,750,999,6,1,4)
CALL PRINTV(8,' DEGREES',806, 999)
CALL AICRT3(KXP,KYP, PLYX, PLYY,NPP,NDP,NVP,NSP,NCP, TITLE,
ØRDXX, ØRDYY,NFP,NGP,DCXP,DCYP,NXØP,XLP,XUP,NYØP,YLP,YUP)
CALL PRINTV(3,'EL ',718,1015)
CALL LABLV(DPLT,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)
CALL PRINTV(3,'AZ ',718, 999)

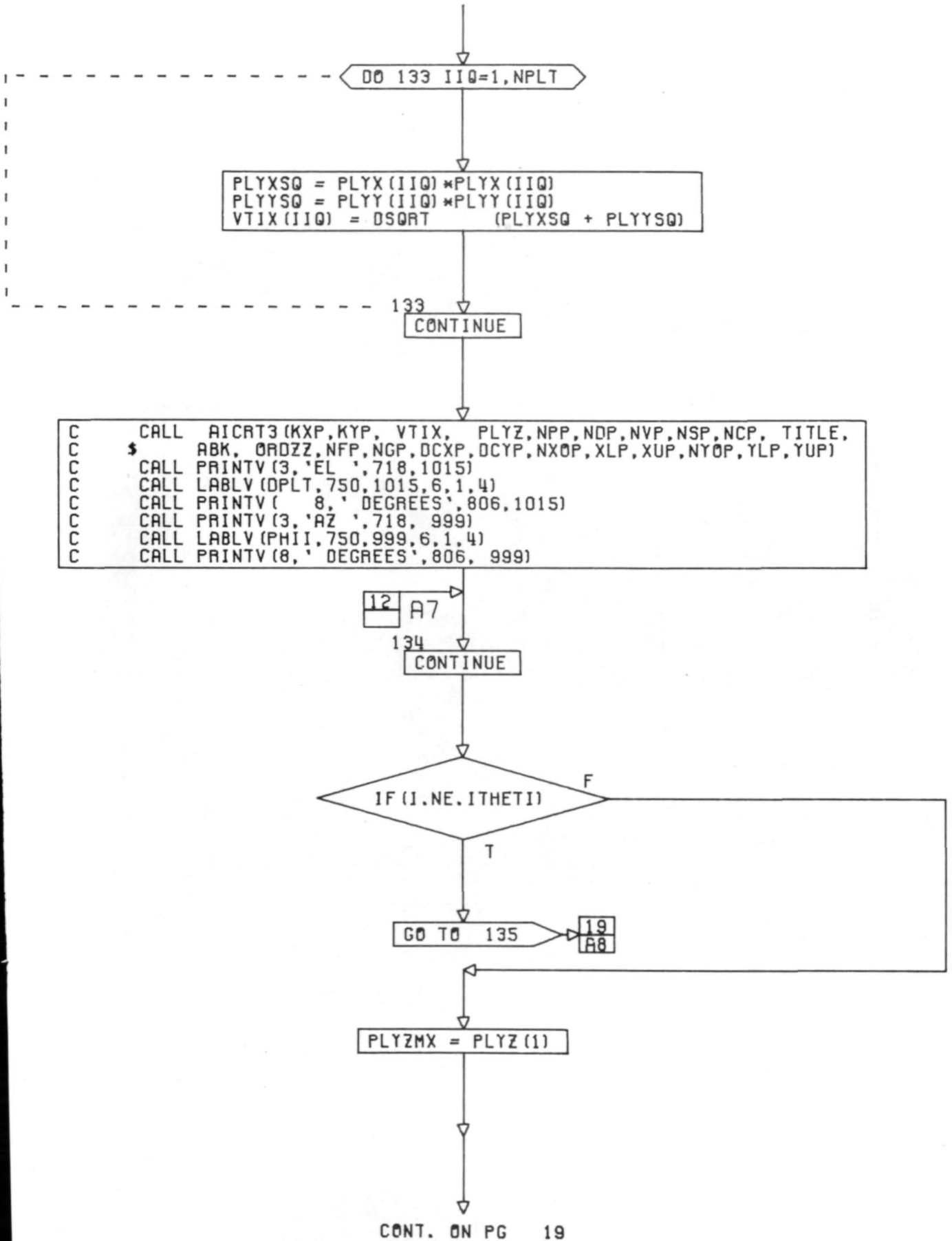
CONT. ØN PG 16

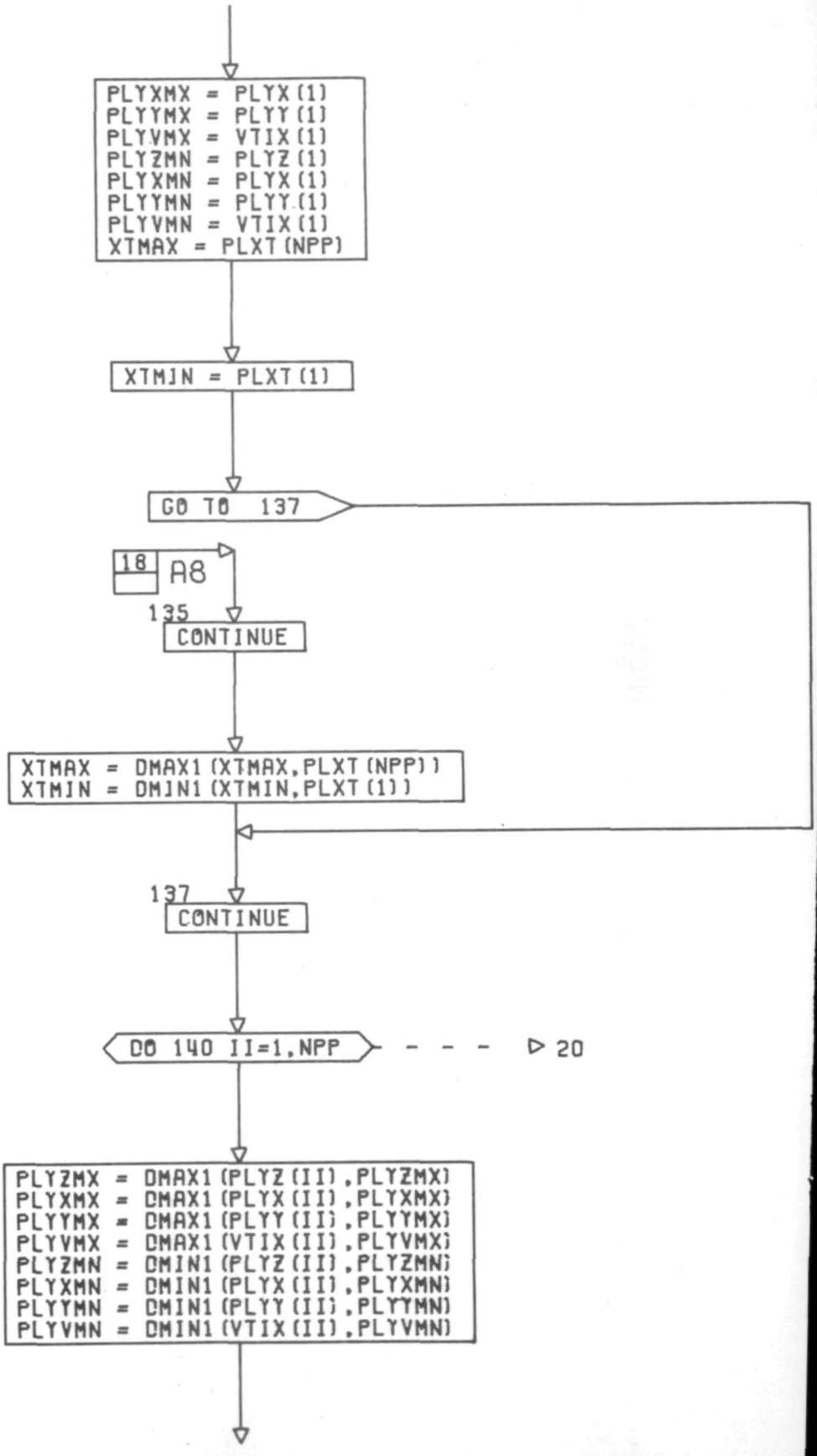

CALL LABLV(PHII,750,999,6,1,4)
CALL PRINTV(8,' DEGREES',806, 999)
CALL AICRT3(KXP,KYP, PLYX, PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,
ORDXX, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CALL PRINTV(3,'EL ',718,1015)
CALL LABLV(DPLT,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)
CALL PRINTV(3,'AZ ',718, 999)
CALL LABLV(PHII,750,999,6,1,4)

CONT. ON PG 17

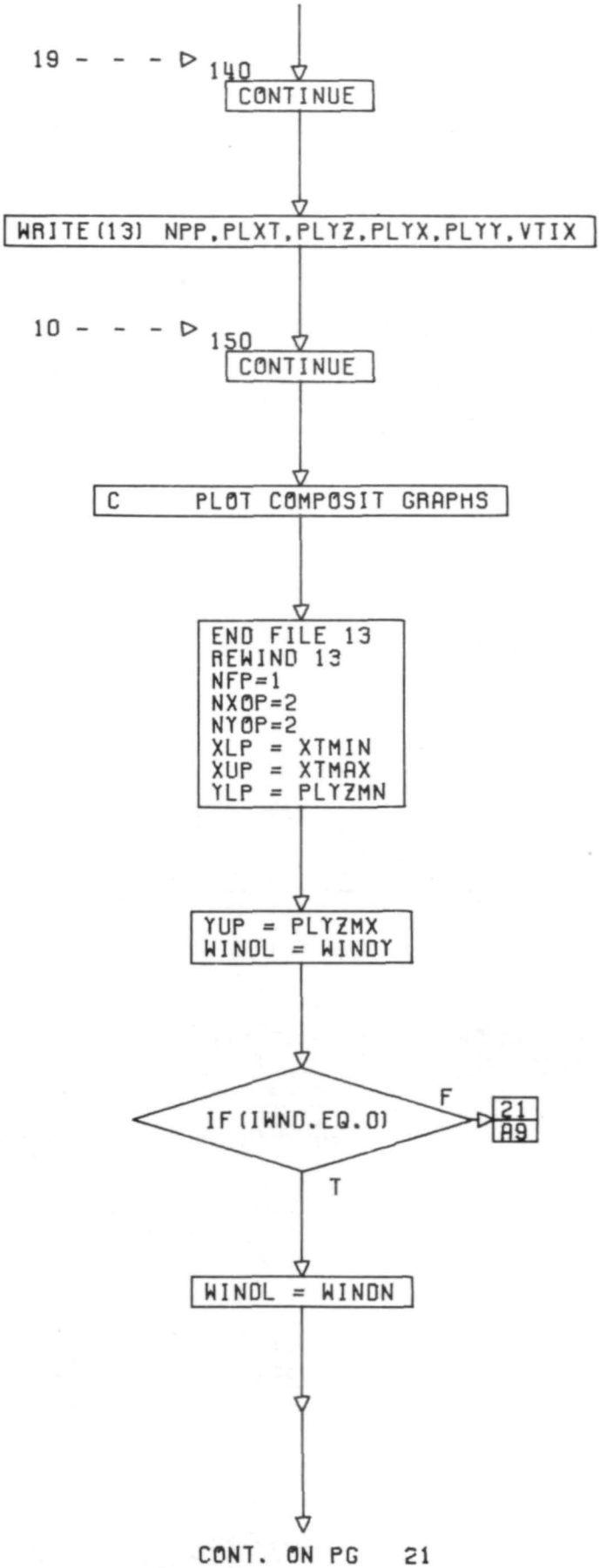

CALL PRINTV(8,' DEGREES',806, 999)
CALL AICRT3(KXP,KYP, PLYY, PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,
ORDYY, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
CALL PRINTV(3,'EL ',718,1015)
CALL LABLV(OPLT,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)
CALL PRINTV(3,'AZ ',718, 999)
CALL LABLV(PHII,750,999,6,1,4)
CALL PRINTV(8,' DEGREES',806, 999)

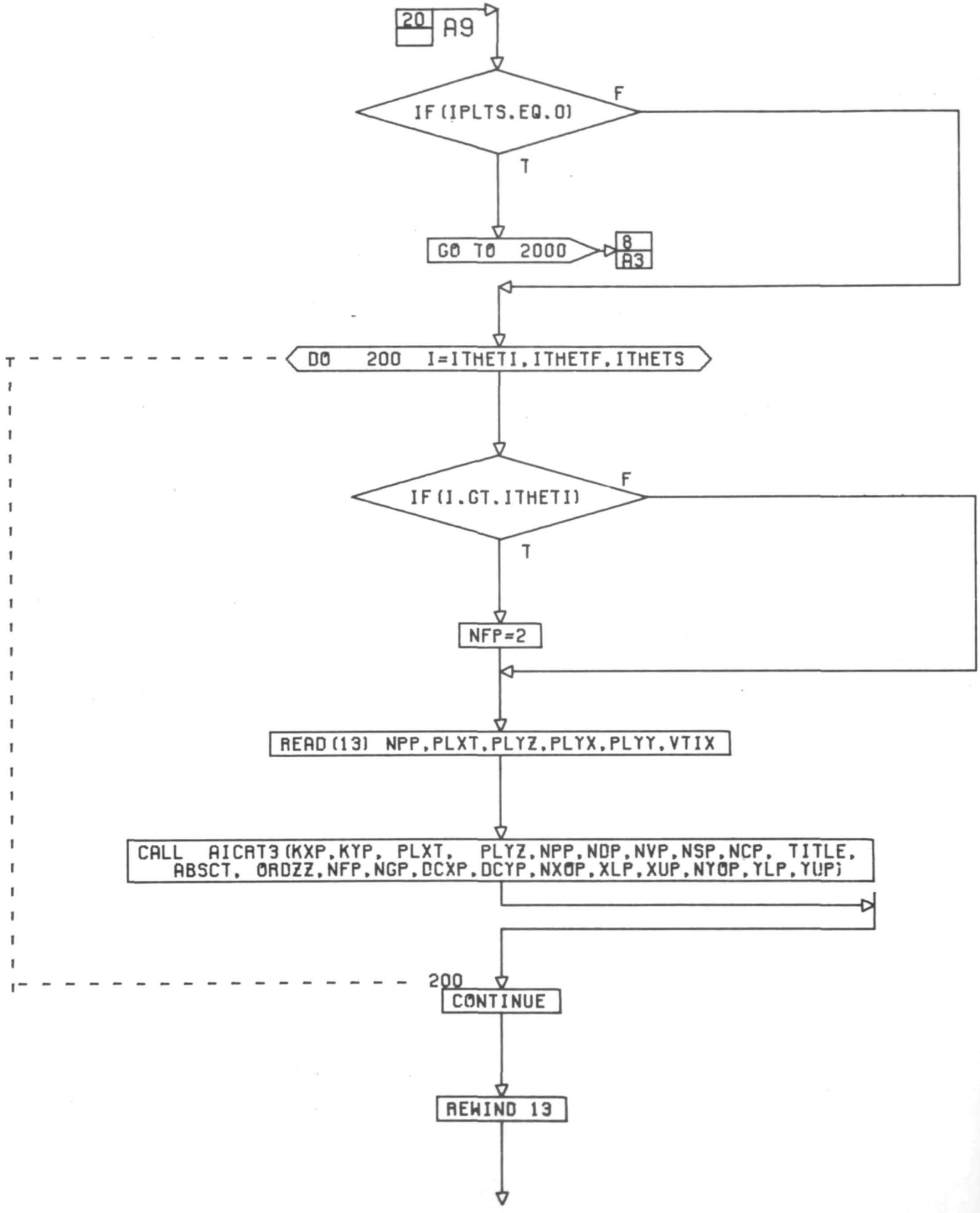
CONT. ON PG 18


DO 133 IIQ=1,NPLT
PLYXSQ = PLYX(IIQ)*PLYX(IIQ)
PLYYSQ = PLYY(IIQ)*PLYY(IIQ)
VTIX(IIQ) = DSQRT (PLYXSQ + PLYYSQ)
133 CONTINUE
C CALL AICRT3(KXP,KYP, VTIX, PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,
C $ ABK, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
C CALL PRINTV(3,'EL ',718,1015)
C CALL LABLV(DPLT,750,1015,6,1,4)
C CALL PRINTV(8,' DEGREES',806,1015)
C CALL PRINTV(3,'AZ ',718, 999)
C CALL LABLV(PHII,750,999,6,1,4)
C CALL PRINTV(8,' DEGREES',806, 999)
12 A7
134 CONTINUE
IF(I.NE.ITHETI)
F
T
GO TO 135
19 A8
PLYZMX = PLYZ(1)
CONT. ON PG 19

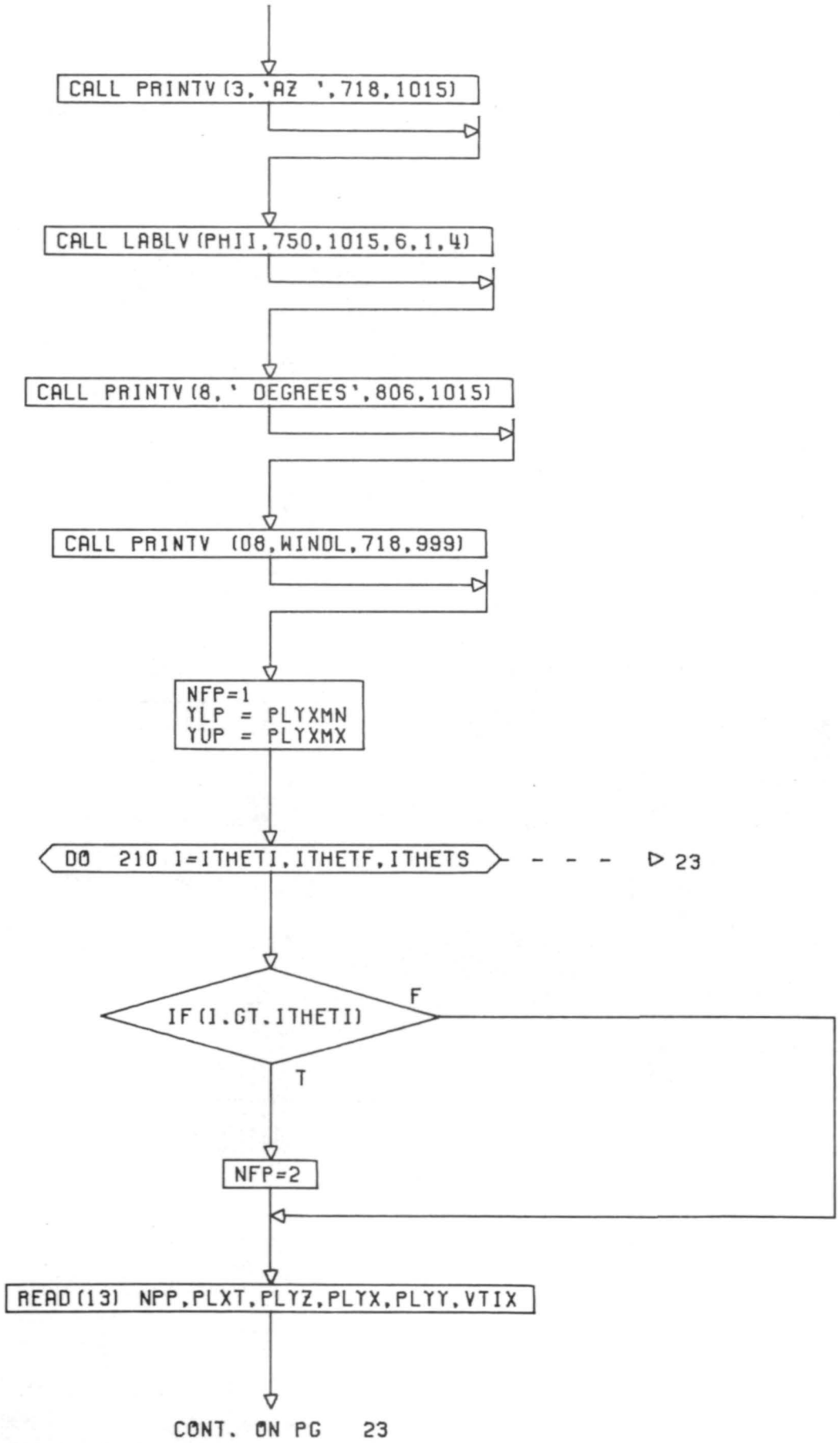

PLYXMX = PLYX(1)
PLYYMX = PLYY(1)
PLYVMX = VTIX(1)
PLYZMN = PLYZ(1)
PLYXMN = PLYX(1)
PLYYMN = PLYY(1)
PLYVMN = VTIX(1)
XTMAX = PLXT(NPP)
XTMIN = PLXT(1)
GO TO 137
18
A8
135
CONTINUE
XTMAX = DMAX1(XTMAX,PLXT(NPP))
XTMIN = DMIN1(XTMIN,PLXT(1))
137
CONTINUE
DO 140 II=1,NPP
20
PLYZMX = DMAX1(PLYZ(II),PLYZMX)
PLYXMX = DMAX1(PLYX(II),PLYXMX)
PLYYMX = DMAX1(PLYY(II),PLYYMX)
PLYVMX = DMAX1(VTIX(II),PLYVMX)
PLYZMN = DMIN1(PLYZ(II),PLYZMN)
PLYXMN = DMIN1(PLYX(II),PLYXMN)
PLYYMN = DMIN1(PLYY(II),PLYYMN)
PLYVMN = DMIN1(VTIX(II),PLYVMN)

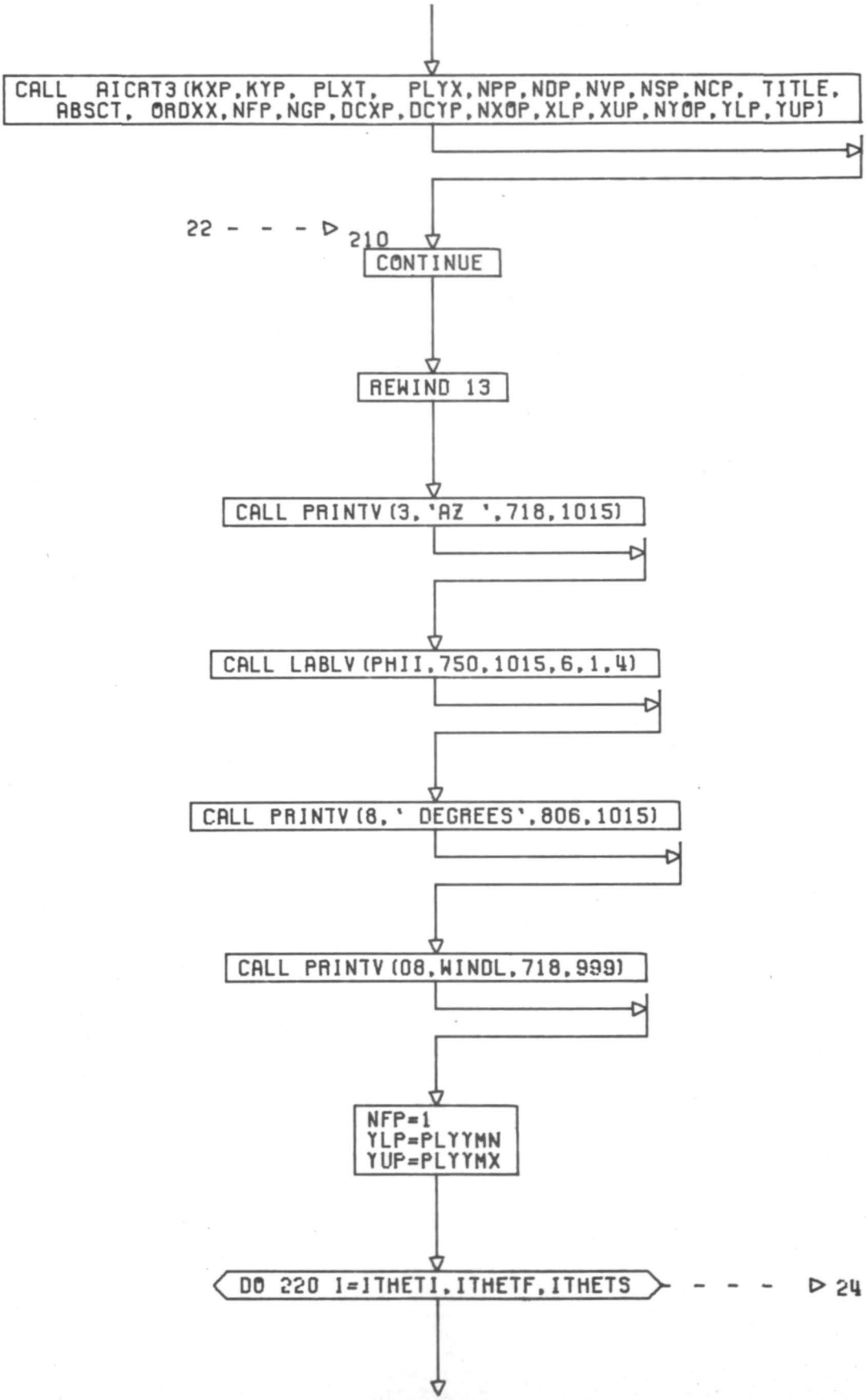
CONT. ON PG 20


19 - - - ▷
140 CONTINUE
WRITE(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX
10 - - - ▷
150 CONTINUE
C PLOT COMPOSIT GRAPHS
END FILE 13
REWIND 13
NFP=1
NXOP=2
NYOP=2
XLP = XTMIN
XUP = XTMAX
YLP = PLYZMN
YUP = PLYZMX
WINDL = WINDY
IF(IWND.EQ.0)
F
21
A9
T
WINDL = WINON
CONT. ON PG 21

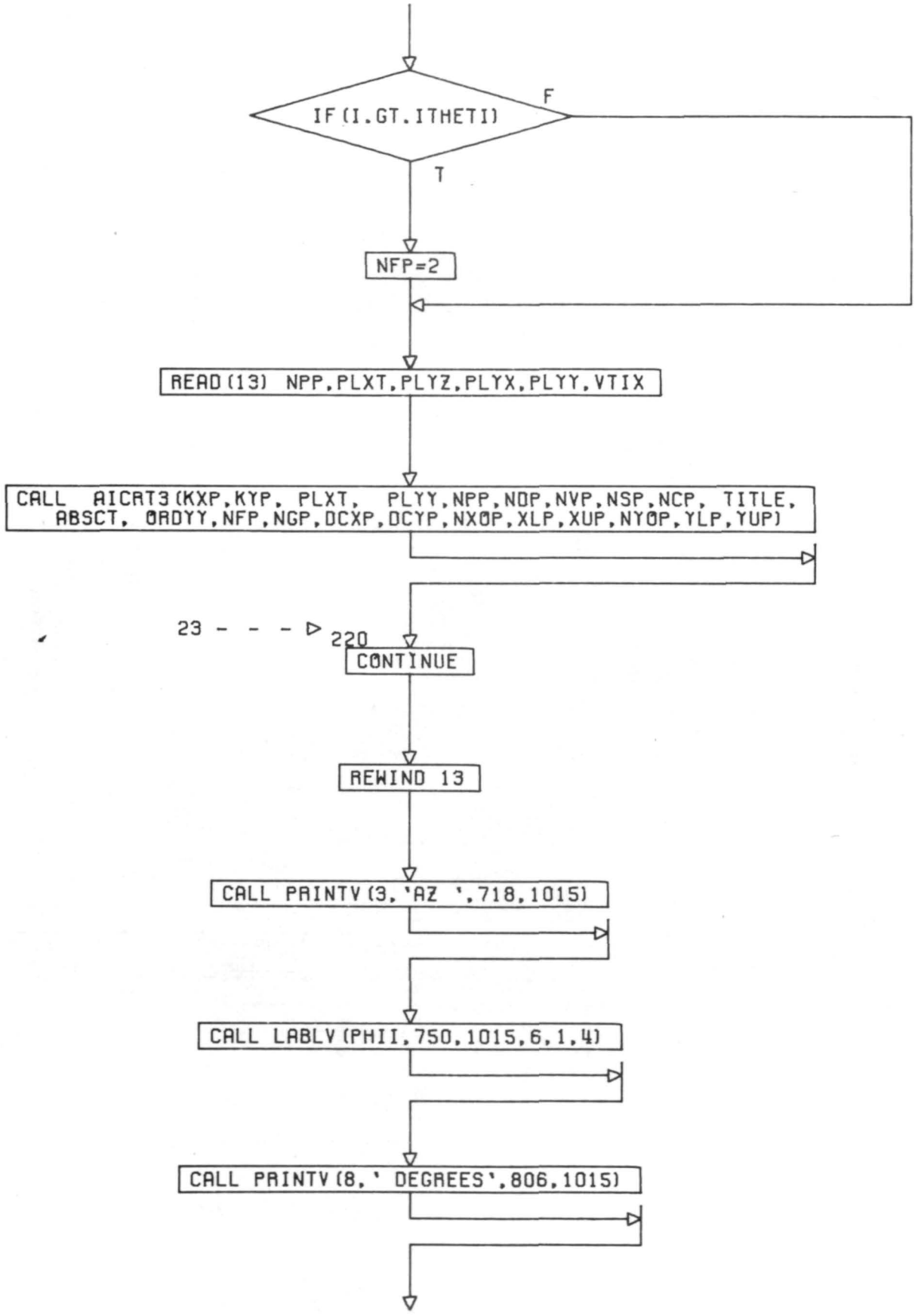

20
A9
IF(IPLTS.EQ.0)
F
T
GO TO 2000
8
A3
DO 200 I=ITHETI,ITHETF,ITHETS
IF(I.GT.ITHETI)
F
T
NFP=2
READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX
CALL AICRT3(KXP,KYP, PLXT, PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,
ABSCT, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
200
CONTINUE
REWIND 13

CONT. ON PG 22

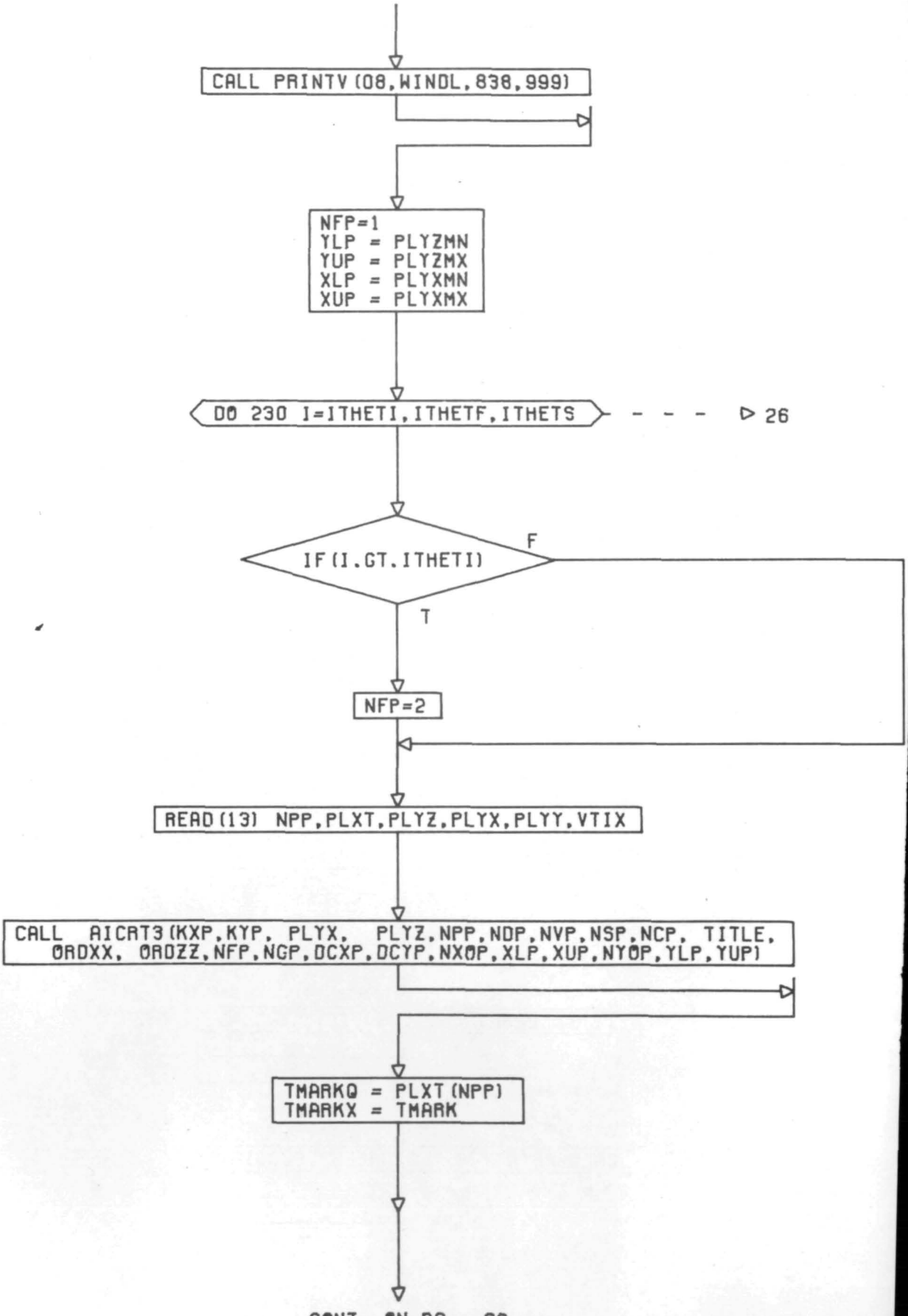

CALL PRINTV(3,'AZ ',718,1015)
CALL LABLV(PHII,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)
CALL PRINTV (08,WINDL,718,999)
NFP=1
YLP = PLYXMN
YUP = PLYXMX
DO 210 I=ITHETI,ITHETF,ITHETS
23
IF(I.GT.ITHETI)
F
T
NFP=2
READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX
CONT. ON PG 23

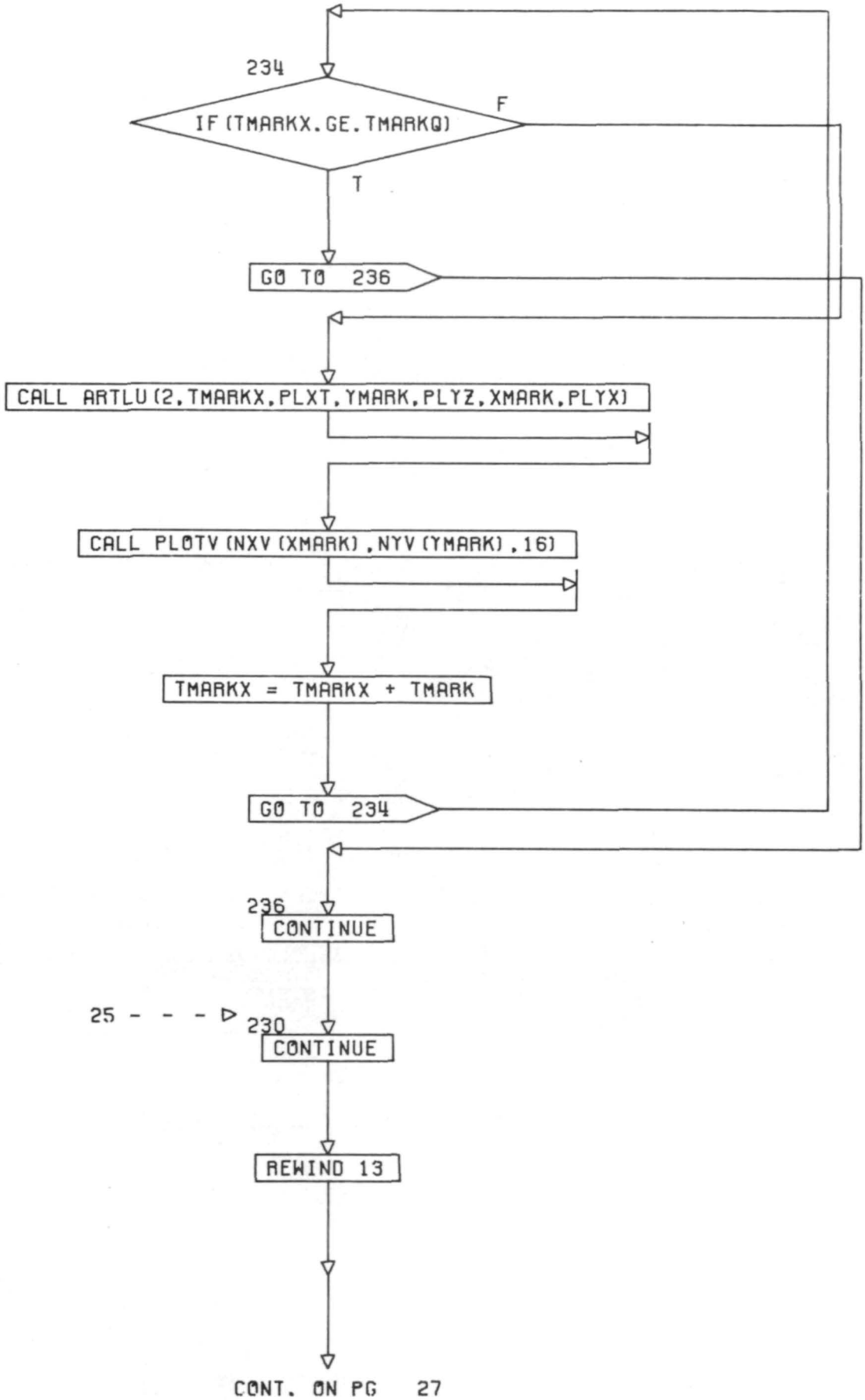

CALL AICRT3(KXP,KYP, PLXT, PLYX,NPP,NDP,NVP,NSP,NCP, TITLE,
ABSCT, ORDXX,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
22 - - - ▷ 210
CONTINUE
REWIND 13
CALL PRINTV(3,'AZ ',718,1015)
CALL LABLV(PHII,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)
CALL PRINTV(08,WINDL,718,999)
NFP=1
YLP=PLYYMN
YUP=PLYYMX
DO 220 I=ITHETI,ITHETF,ITHETS
- - - ▷ 24

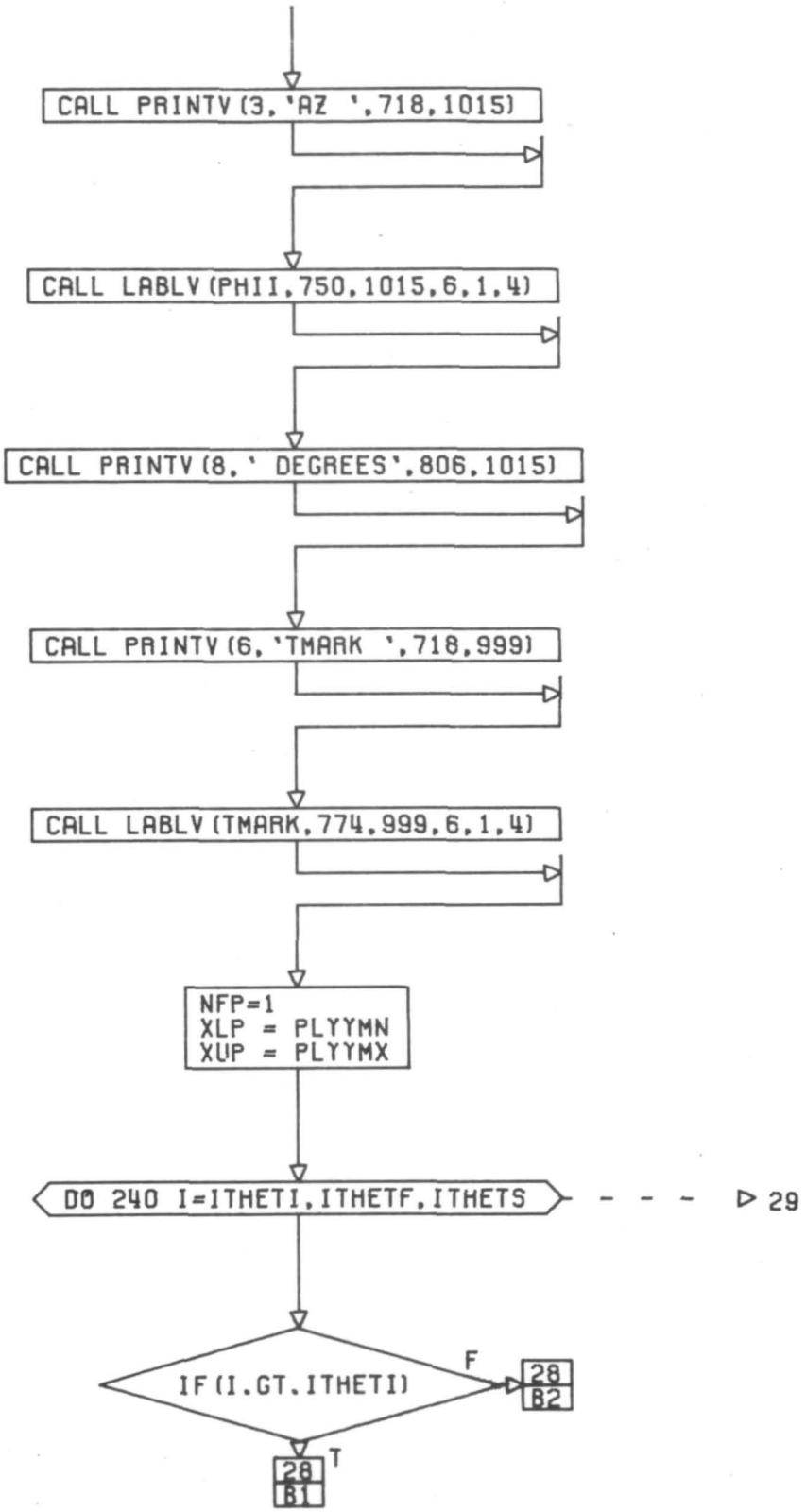
CONT. ON PG 24


IF(I.GT.ITHETI)
F
T
NFP=2
READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX
CALL AICRT3(KXP,KYP, PLXT, PLYY,NPP,NOP,NVP,NSP,NCP, TITLE,
ABSCT, ORDYY,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
23 - - - ▷ 220
CONTINUE
REWIND 13
CALL PRINTV(3,'AZ ',718,1015)
CALL LABLV(PHII,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)

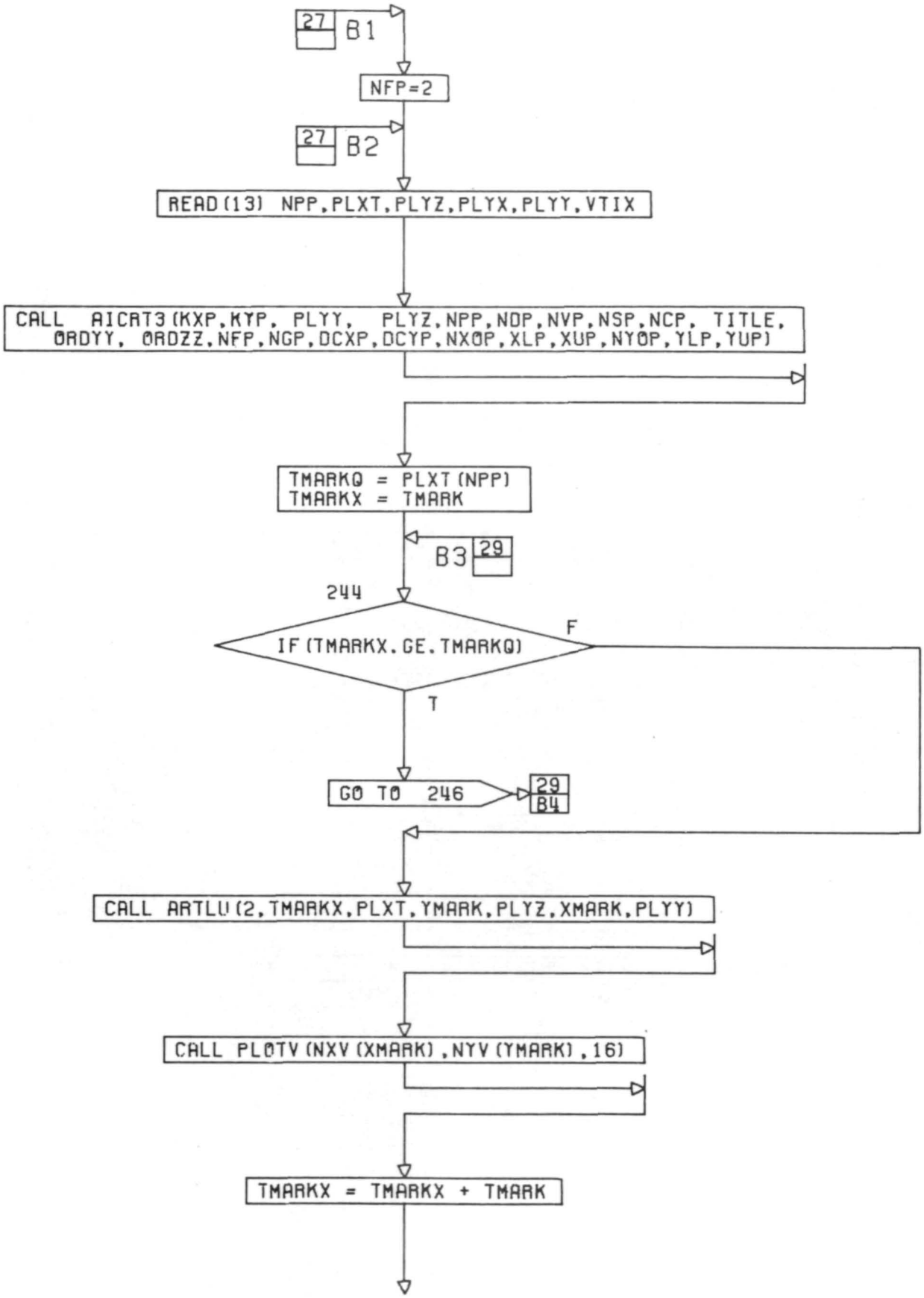
CONT. ON PG 25


CALL PRINTV(08,WINDL,838,999)
NFP=1
YLP = PLYZMN
YUP = PLYZMX
XLP = PLYXMN
XUP = PLYXMX
DO 230 I=ITHETI,ITHETF,ITHETS
▷ 26
IF(I.GT.ITHETI)
F
T
NFP=2
READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX
CALL AICRT3(KXP,KYP, PLYX, PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,
ORDXX, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
TMARKQ = PLXT(NPP)
TMARKX = TMARK
CONT. ON PG 26

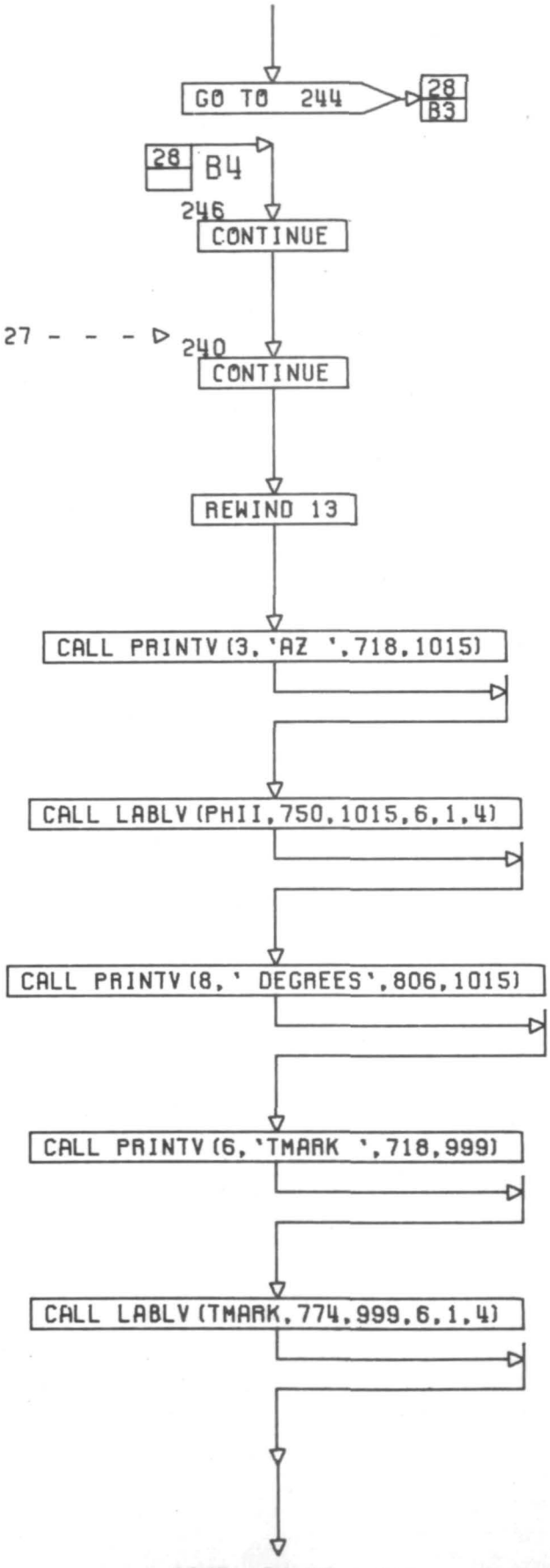

234
IF (TMARKX.GE.TMARKQ)
F
T
GO TO 236
CALL ARTLU(2,TMARKX,PLXT,YMARK,PLYZ,XMARK,PLYX)
CALL PLOTV(NXV(XMARK),NYV(YMARK),16)
TMARKX = TMARKX + TMARK
GO TO 234
236
CONTINUE
25
230
CONTINUE
REWIND 13
CONT. ON PG 27


CALL PRINTV(3,'AZ ',718,1015)
CALL LABLV(PHII,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)
CALL PRINTV(6,'TMARK ',718,999)
CALL LABLV(TMARK,774,999,6,1,4)
NFP=1
XLP = PLYYMN
XUP = PLYYMX
DO 240 I=ITHETI,ITHETF,ITHETS
▷ 29
IF(I.GT.ITHETI)
F
28
B2
T
28
B1

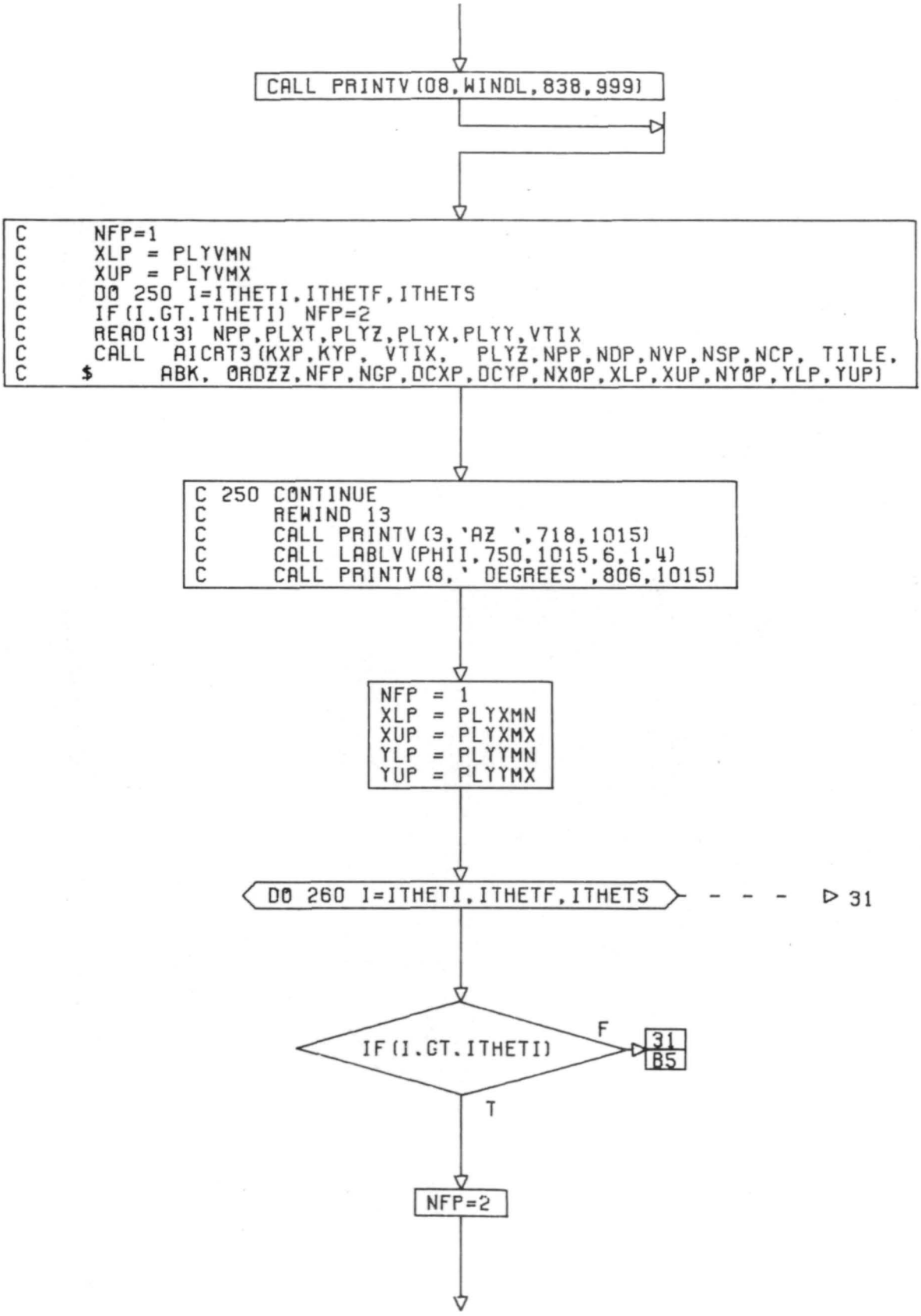
CONT. ON PG 28


27
B1
NFP=2
27
B2
READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX
CALL AICRT3(KXP,KYP, PLYY, PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,
ORDYY, ORDZZ,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
TMARKQ = PLXT(NPP)
TMARKX = TMARK
B3
29
244
IF(TMARKX.GE.TMARKQ)
F
T
GO TO 246
29
B4
CALL ARTLU(2,TMARKX,PLXT,YMARK,PLYZ,XMARK,PLYY)
CALL PLOTV(NXV(XMARK),NYV(YMARK),16)
TMARKX = TMARKX + TMARK

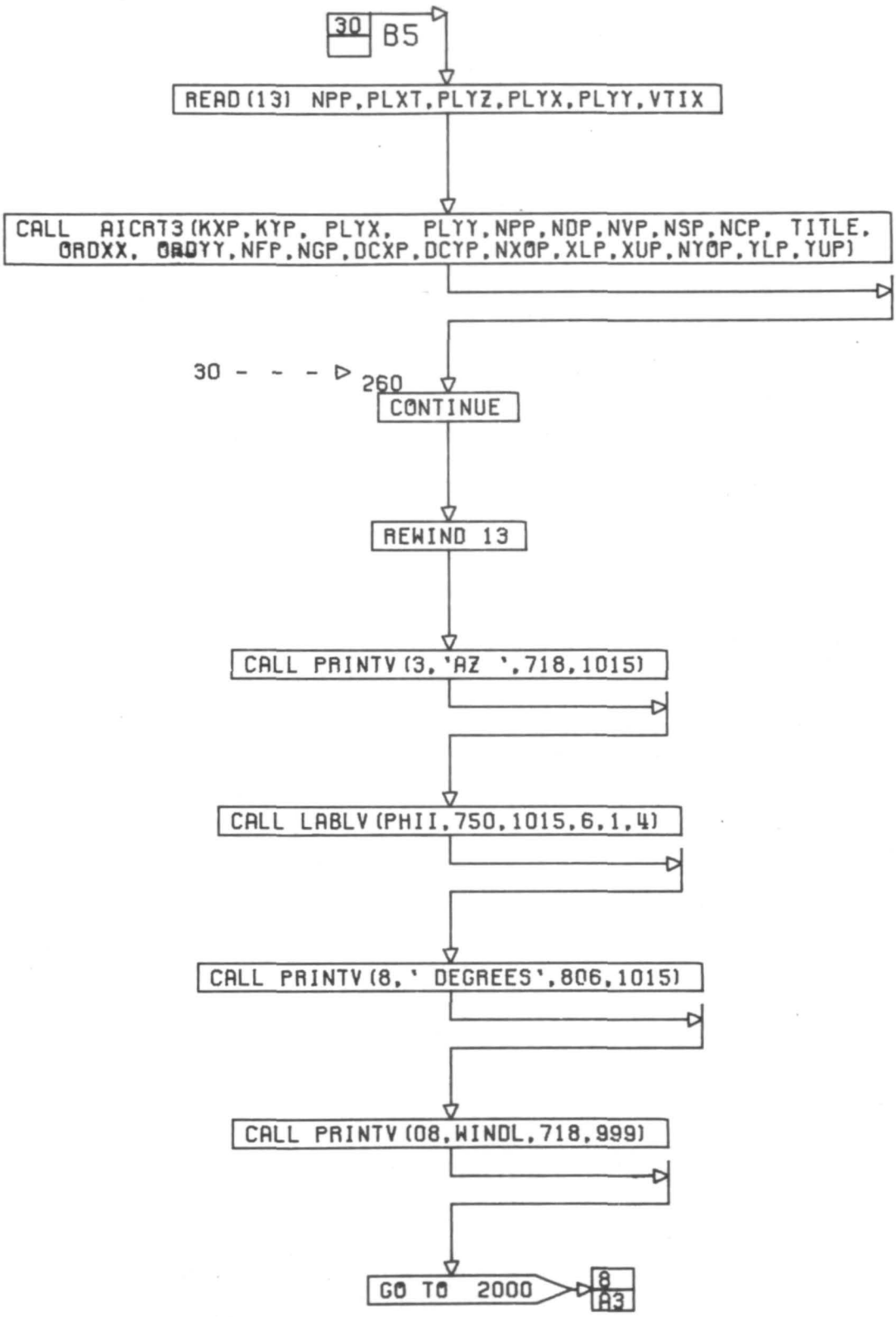
CONT. ON PG 29


GO TO 244
28
B3
28
B4
246
CONTINUE
27 - - - -
240
CONTINUE
REWIND 13
CALL PRINTV(3,'AZ ',718,1015)
CALL LABLV(PHII,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)
CALL PRINTV(6,'TMARK ',718,999)
CALL LABLV(TMARK,774,999,6,1,4)

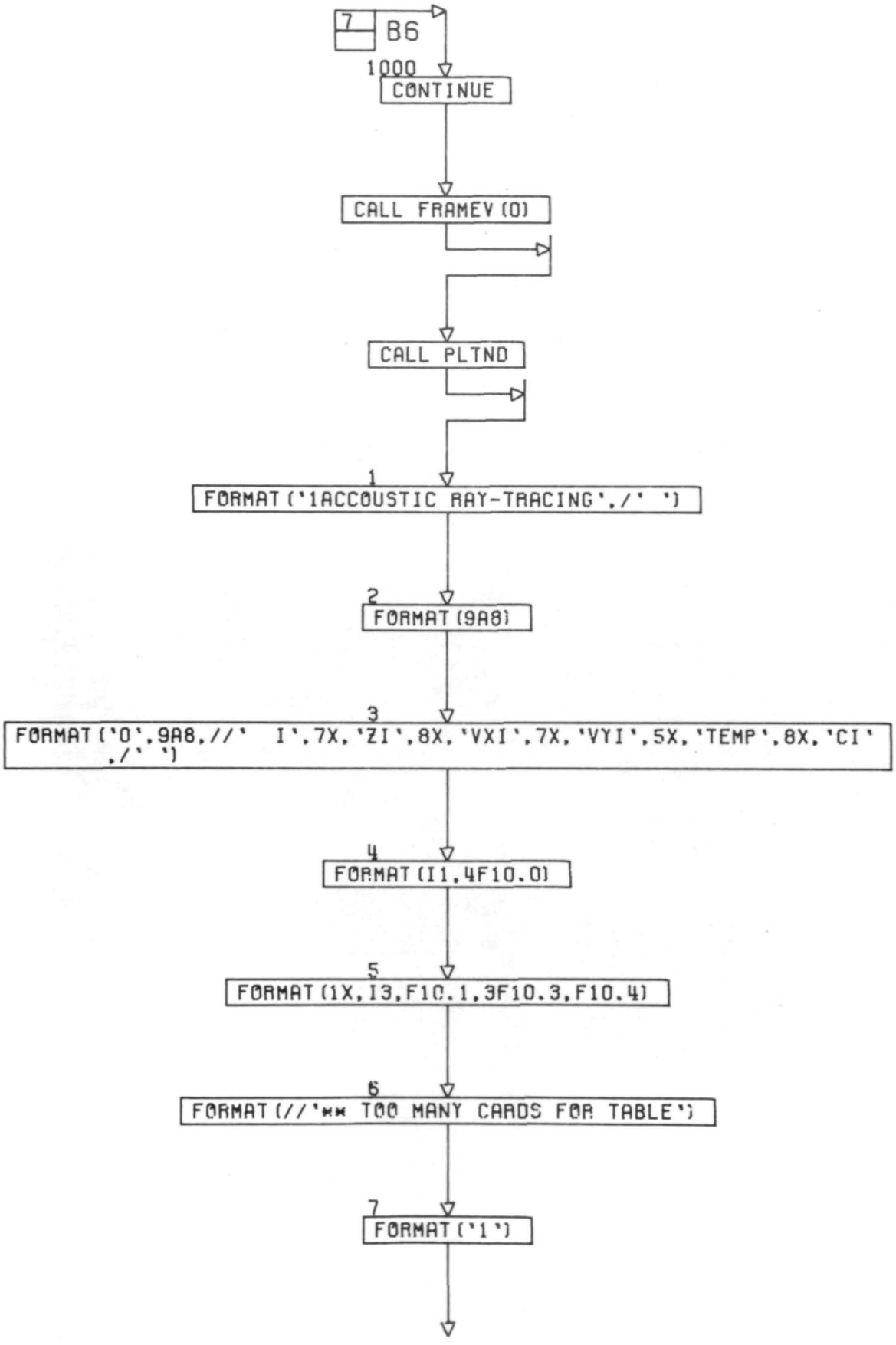
CONT. ON PG 30


CALL PRINTV(08,WINDL,838,999)
C NFP=1
C XLP = PLYVMN
C XUP = PLYVMX
C DO 250 I=ITHETI,ITHETF,ITHETS
C IF(I.GT.ITHETI) NFP=2
C READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX
C CALL AICRT3(KXP,KYP, VTIX, PLYZ,NPP,NDP,NVP,NSP,NCP, TITLE,
C $ ABK, ORDZZ,NFP,NGP,DCXP,DCYP,NX0P,XLP,XUP,NY0P,YLP,YUP)
C 250 CONTINUE
C REWIND 13
C CALL PRINTV(3,'AZ ',718,1015)
C CALL LABLV(PHII,750,1015,6,1,4)
C CALL PRINTV(8,' DEGREES',806,1015)
NFP = 1
XLP = PLYXMN
XUP = PLYXMX
YLP = PLYYMN
YUP = PLYYMX
DO 260 I=ITHETI,ITHETF,ITHETS
▷ 31
IF(I.GT.ITHETI)
F
31
B5
T
NFP=2

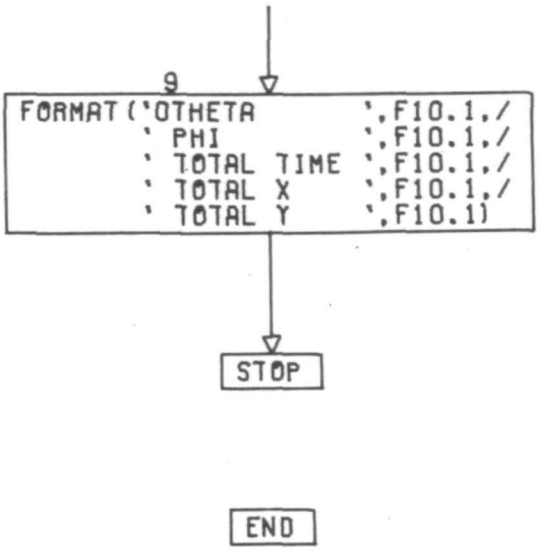
CONT. ON PG 31

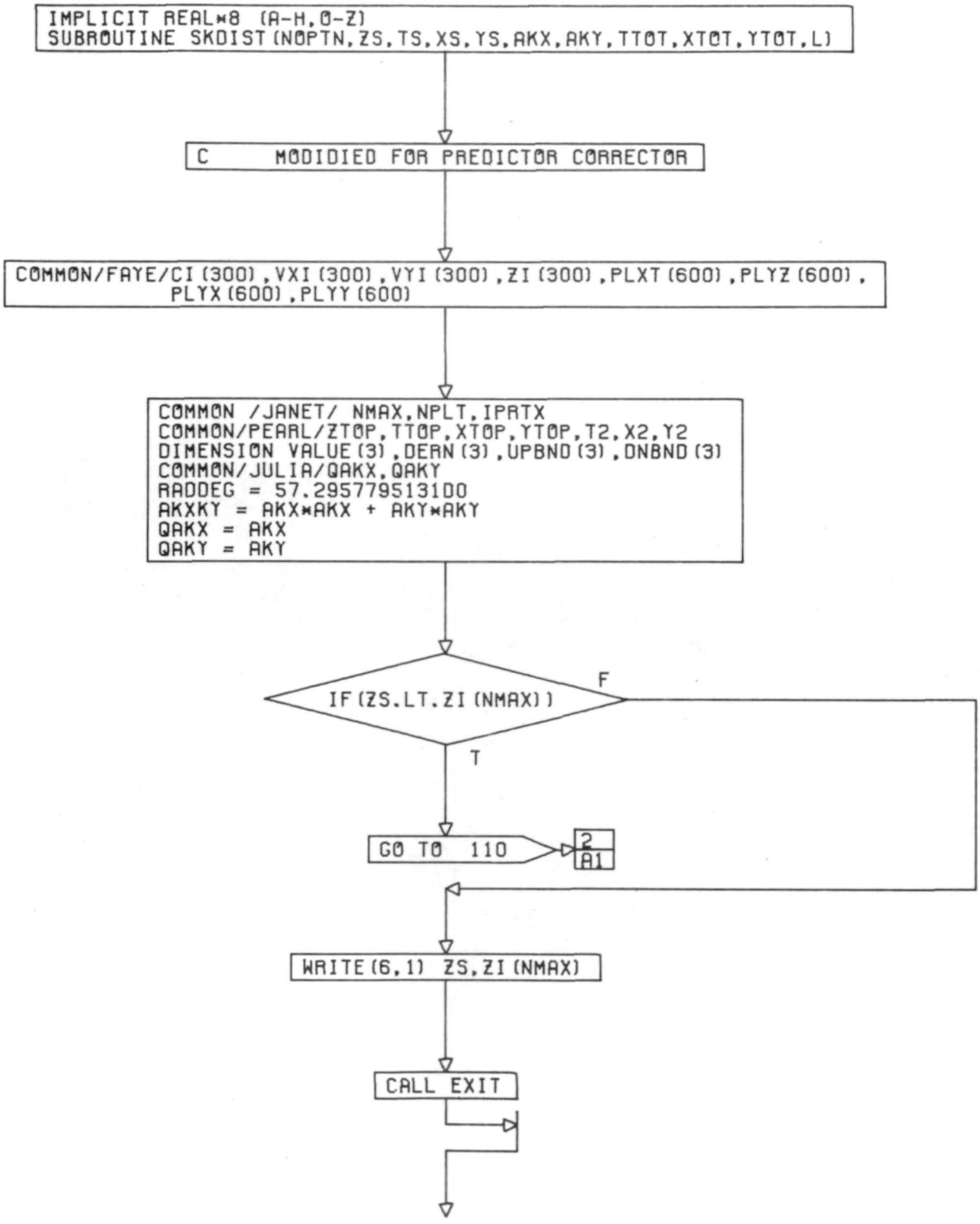

30
B5
READ(13) NPP,PLXT,PLYZ,PLYX,PLYY,VTIX
CALL AICRT3(KXP,KYP, PLYX, PLYY,NPP,NDP,NVP,NSP,NCP, TITLE,
ORDXX, ORDYY,NFP,NGP,DCXP,DCYP,NXOP,XLP,XUP,NYOP,YLP,YUP)
30 - - - ▷ 260
CONTINUE
REWIND 13
CALL PRINTV(3,'AZ ',718,1015)
CALL LABLV(PHII,750,1015,6,1,4)
CALL PRINTV(8,' DEGREES',806,1015)
CALL PRINTV(08,WINDL,718,999)
GO TO 2000
8
A3

CONT. ON PG 32

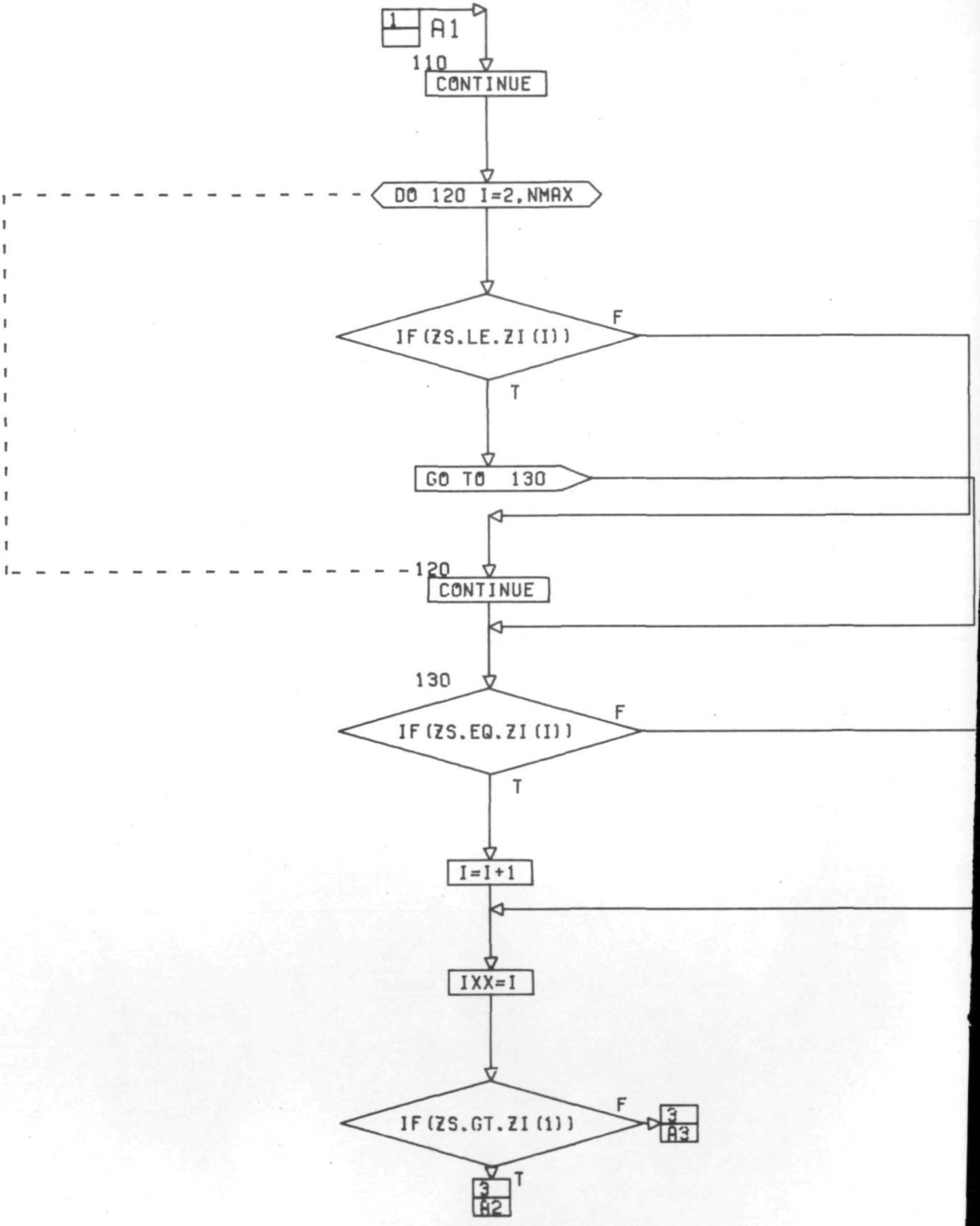

7
B6
1000
CONTINUE
CALL FRAMEV(0)
CALL PLTND
1
FORMAT('1ACCOUSTIC RAY-TRACING',/' ')
2
FORMAT(9A8)
3
FORMAT('0',9A8,//' I',7X,'ZI',8X,'VXI',7X,'VYI',5X,'TEMP',8X,'CI'
,/' ')
4
FORMAT(I1,4F10.0)
5
FORMAT(1X,I3,F10.1,3F10.3,F10.4)
6
FORMAT(//'** TOO MANY CARDS FOR TABLE')
7
FORMAT('1')

CONT. ON PG 33

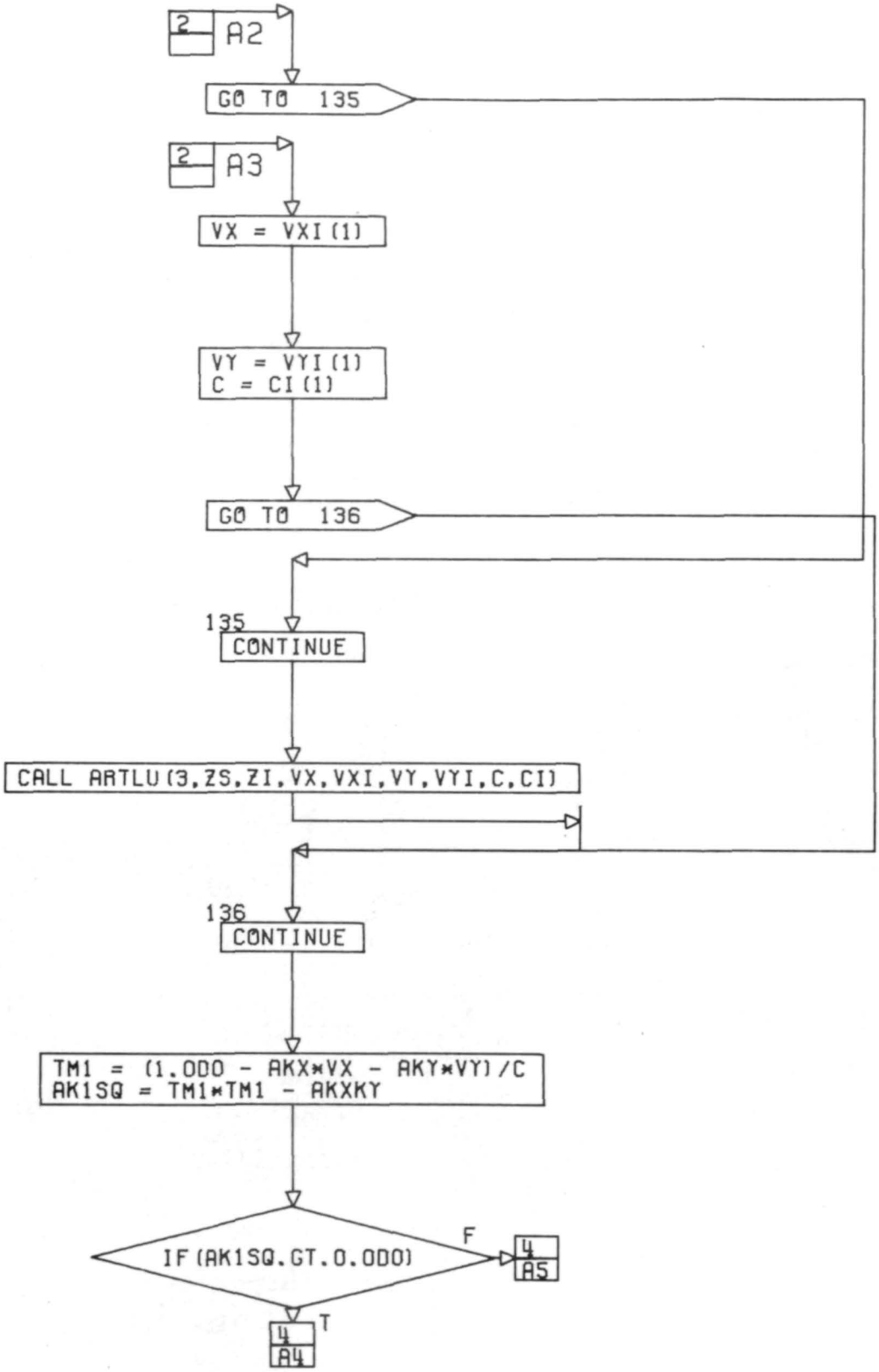

9
FORMAT('OTHETA ',F10.1,/
' PHI ',F10.1,/
' TOTAL TIME ',F10.1,/
' TOTAL X ',F10.1,/
' TOTAL Y ',F10.1)
STOP
END


IMPLICIT REAL*8 (A-H,0-Z)
SUBROUTINE SKDIST(NOPTN,ZS,TS,XS,YS,AKX,AKY,TTOT,XTOT,YTOT,L)
C MODIDIED FOR PREDICTOR CORRECTOR
COMMON/FAYE/CI(300),VXI(300),VYI(300),ZI(300),PLXT(600),PLYZ(600),
PLYX(600),PLYY(600)
COMMON /JANET/ NMAX,NPLT,IPRTX
COMMON/PEARL/ZTOP,TTOP,XTOP,YTOP,T2,X2,Y2
DIMENSION VALUE(3),DERN(3),UPBND(3),DNBND(3)
COMMON/JULIA/QAKX,QAKY
RADDEG = 57.295779513100
AKXKY = AKX*AKX + AKY*AKY
QAKX = AKX
QAKY = AKY
IF(ZS.LT.ZI(NMAX))
F
T
GO TO 110
2
A1
WRITE(6,1) ZS,ZI(NMAX)
CALL EXIT

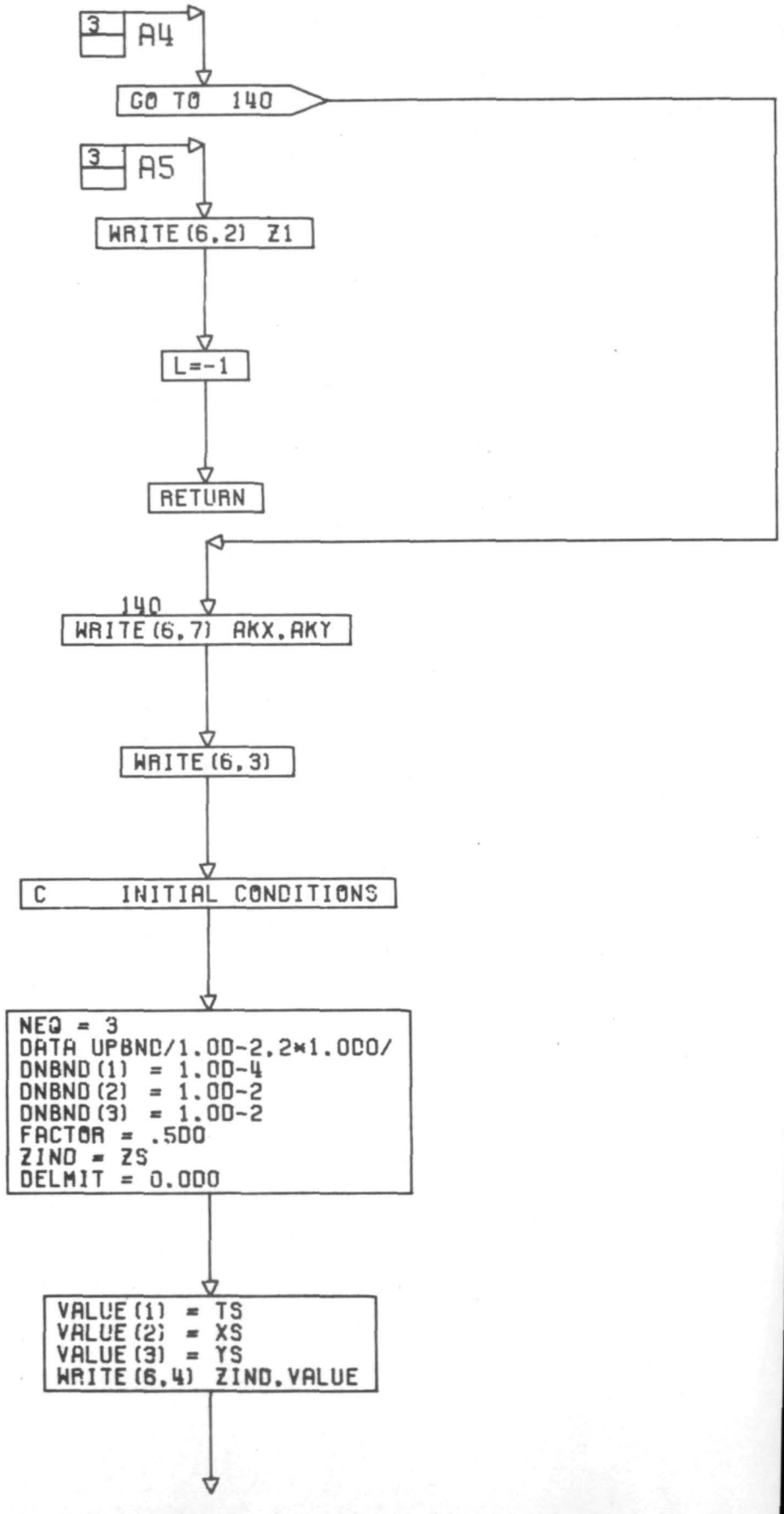
CONT. ON PG 2


1
A1
110
CONTINUE
DO 120 I=2,NMAX
IF(ZS.LE.ZI(I))
F
T
GO TO 130
120
CONTINUE
130
IF(ZS.EQ.ZI(I))
F
T
I=I+1
IXX=I
IF(ZS.GT.ZI(1))
F
3
A3
T
3
A2

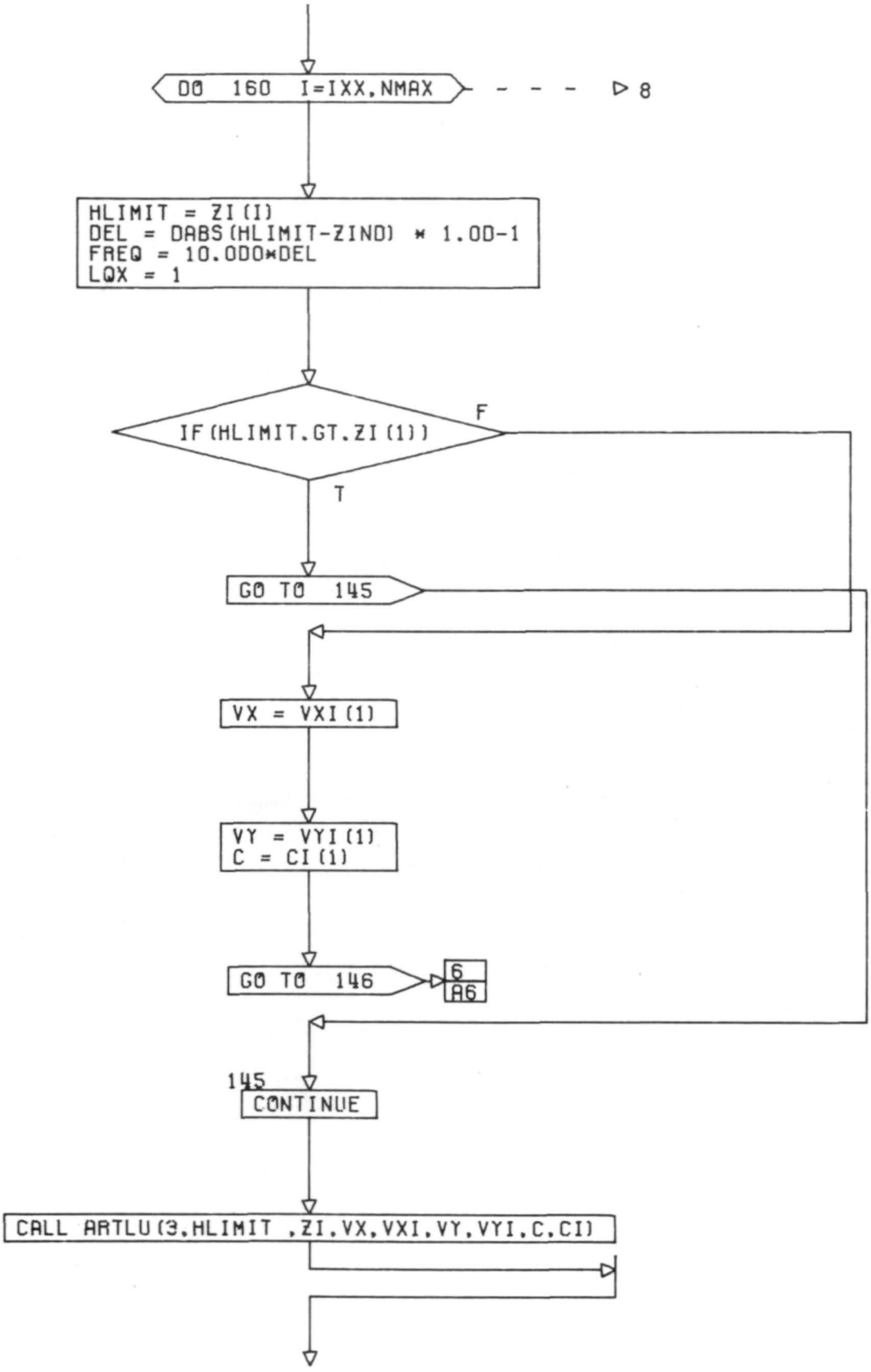
CONT. ON PG 3


2
A2
GO TO 135
2
A3
VX = VXI(1)
VY = VYI(1)
C = CI(1)
GO TO 136
135
CONTINUE
CALL ARTLU(3,ZS,ZI,VX,VXI,VY,VYI,C,CI)
136
CONTINUE
TM1 = (1.0D0 - AKX*VX - AKY*VY)/C
AK1SQ = TM1*TM1 - AKXKY
IF(AK1SQ.GT.0.0D0)
F
4
A5
T
4
A4

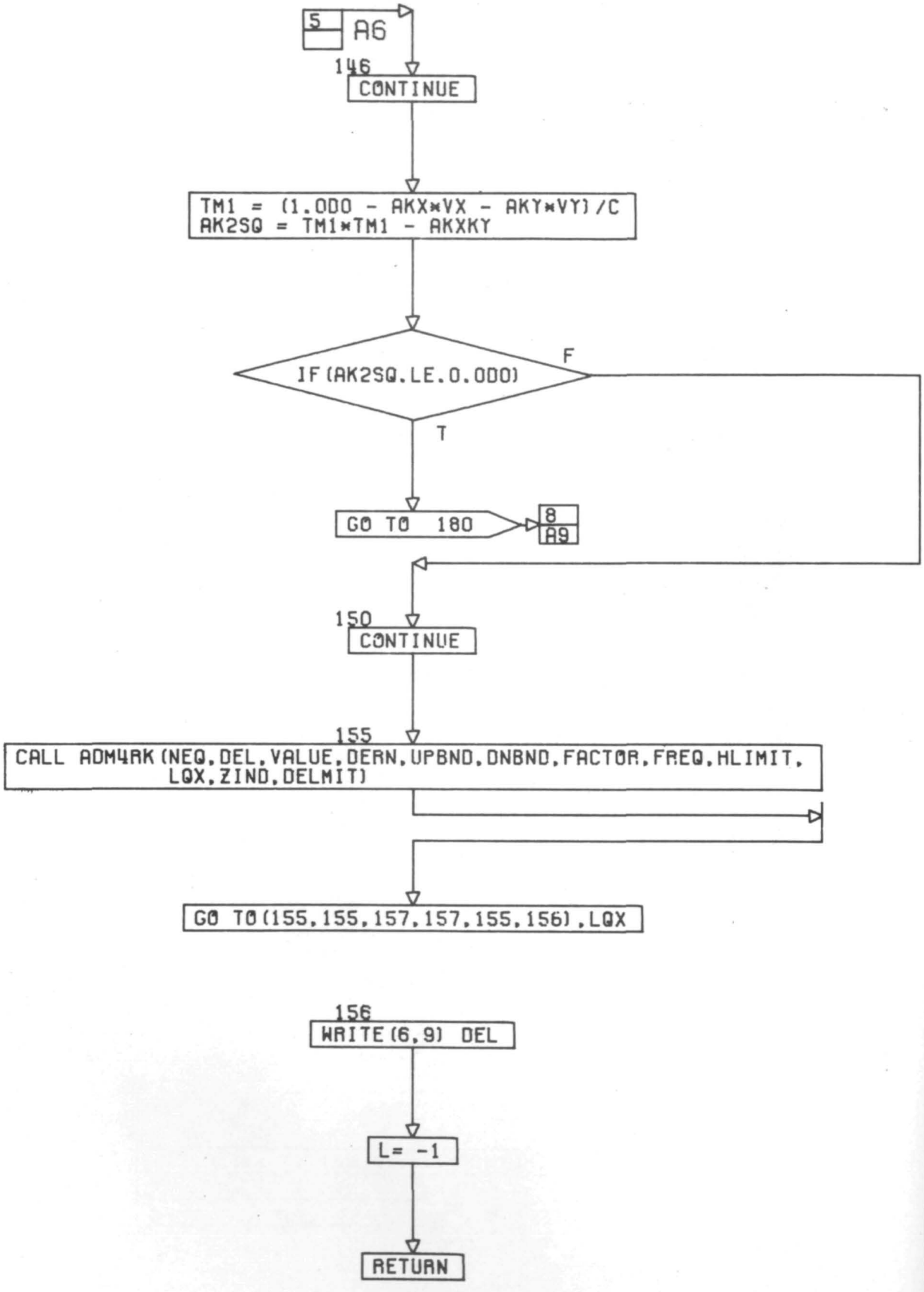
CONT. ON PG 4


3
A4
GO TO 140
3
A5
WRITE(6,2) Z1
L=-1
RETURN
140
WRITE(6,7) AKX,AKY
WRITE(6,3)
C INITIAL CONDITIONS
NEQ = 3
DATA UPBND/1.0D-2,2*1.0D0/
DNBND(1) = 1.0D-4
DNBND(2) = 1.0D-2
DNBND(3) = 1.0D-2
FACTOR = .5D0
ZIND = ZS
DELMIT = 0.0D0
VALUE(1) = TS
VALUE(2) = XS
VALUE(3) = YS
WRITE(6,4) ZIND,VALUE

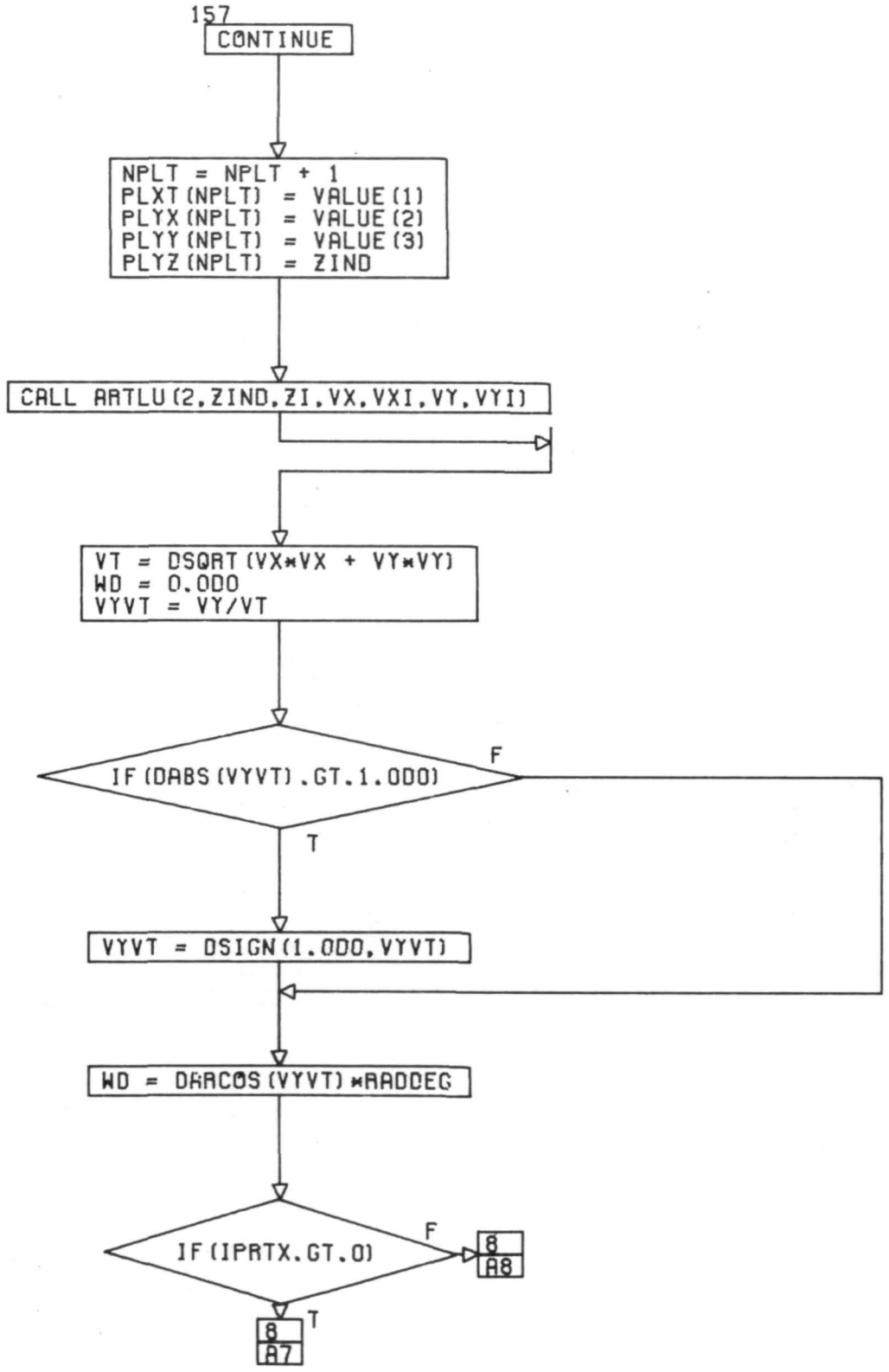
CONT. ON PG 5


DO 160 I=IXX,NMAX
▷ 8
HLIMIT = ZI(I)
DEL = DABS(HLIMIT-ZIND) * 1.0D-1
FREQ = 10.0D0*DEL
LQX = 1
IF(HLIMIT.GT.ZI(1))
F
T
GO TO 145
VX = VXI(1)
VY = VYI(1)
C = CI(1)
GO TO 146
6
A6
145
CONTINUE
CALL ARTLU(3,HLIMIT ,ZI,VX,VXI,VY,VYI,C,CI)

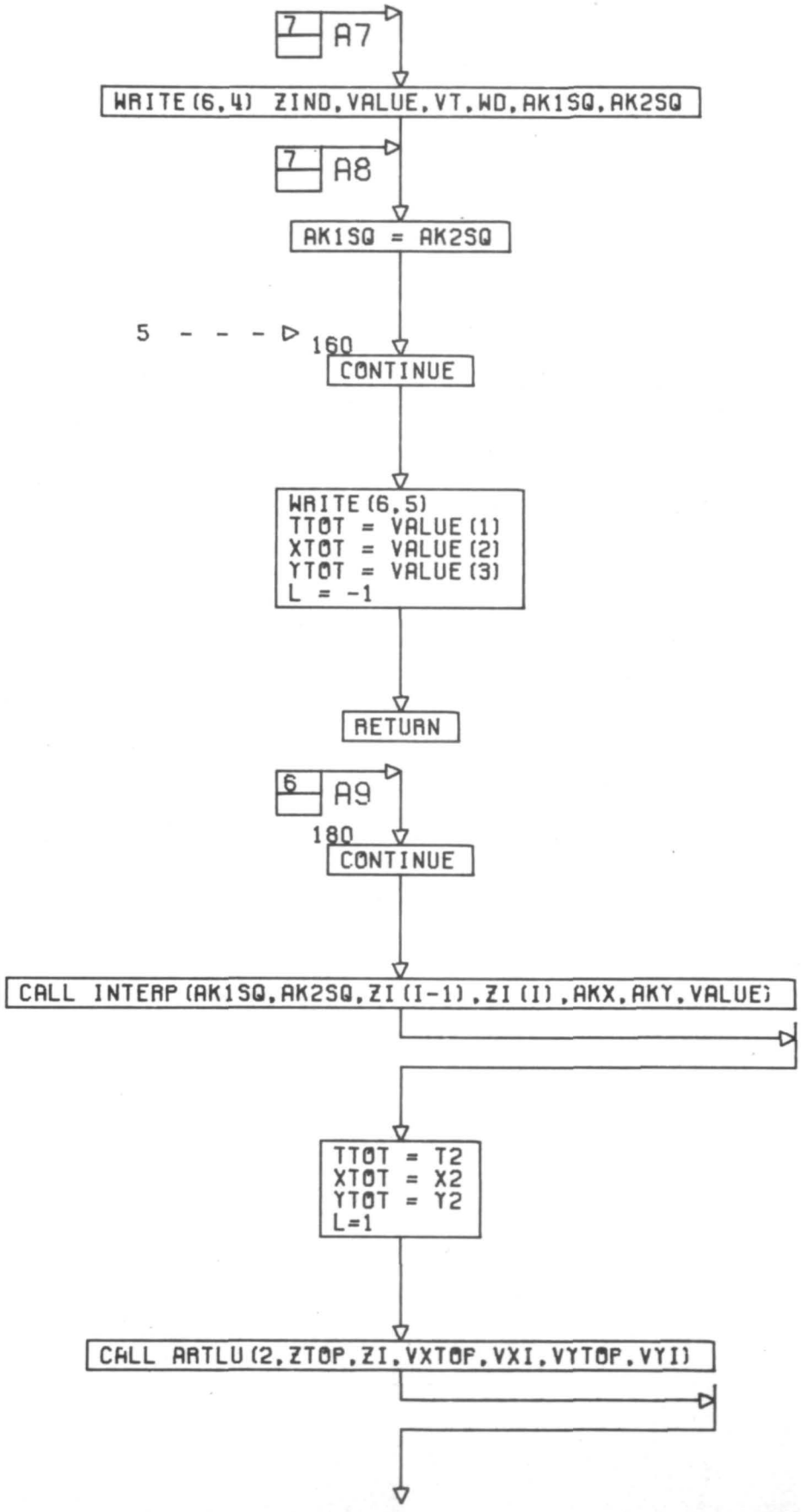
CONT. ON PG 6


5
A6
146
CONTINUE
TM1 = (1.0D0 - AKX*VX - AKY*VY)/C
AK2SQ = TM1*TM1 - AKXKY
IF(AK2SQ.LE.0.0D0)
F
T
GO TO 180
8
A9
150
CONTINUE
155
CALL ADM4RK(NEQ,DEL,VALUE,DERN,UPBND,DNBND,FACTOR,FREQ,HLIMIT,
LQX,ZIND,DELMIT)
GO TO(155,155,157,157,155,156),LQX
156
WRITE(6,9) DEL
L= -1
RETURN

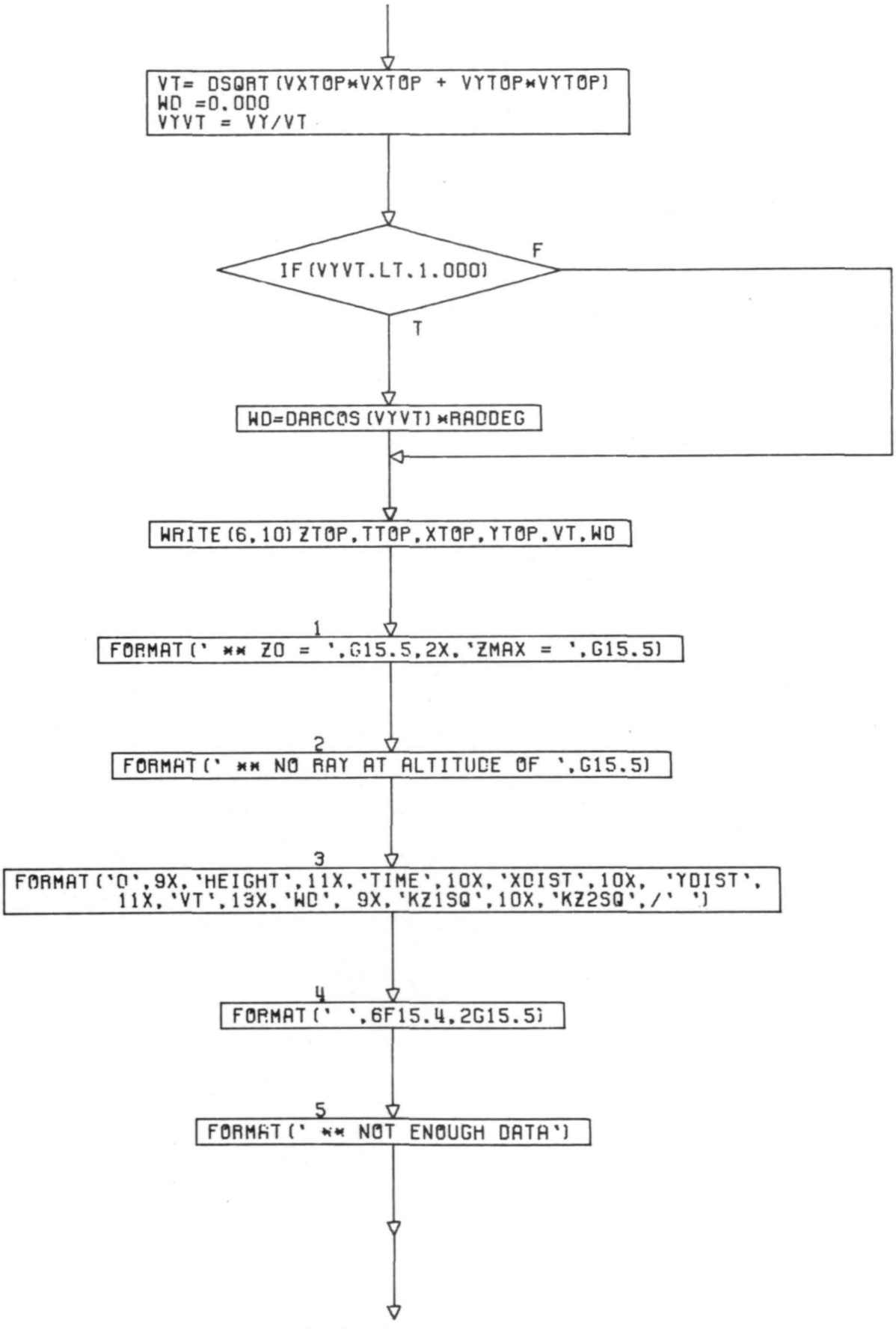
CONT. ON PG 7


157
CONTINUE
NPLT = NPLT + 1
PLXT(NPLT) = VALUE(1)
PLYX(NPLT) = VALUE(2)
PLYY(NPLT) = VALUE(3)
PLYZ(NPLT) = ZIND
CALL ARTLU(2,ZIND,ZI,VX,VXI,VY,VYI)
VT = DSQRT(VX*VX + VY*VY)
WD = 0.0D0
VYVT = VY/VT
IF(DABS(VYVT).GT.1.0D0)
F
T
VYVT = DSIGN(1.0D0,VYVT)
WD = DARCOS(VYVT)*RADDEG
IF(IPRTX.GT.0)
F
8
A8
T
8
A7

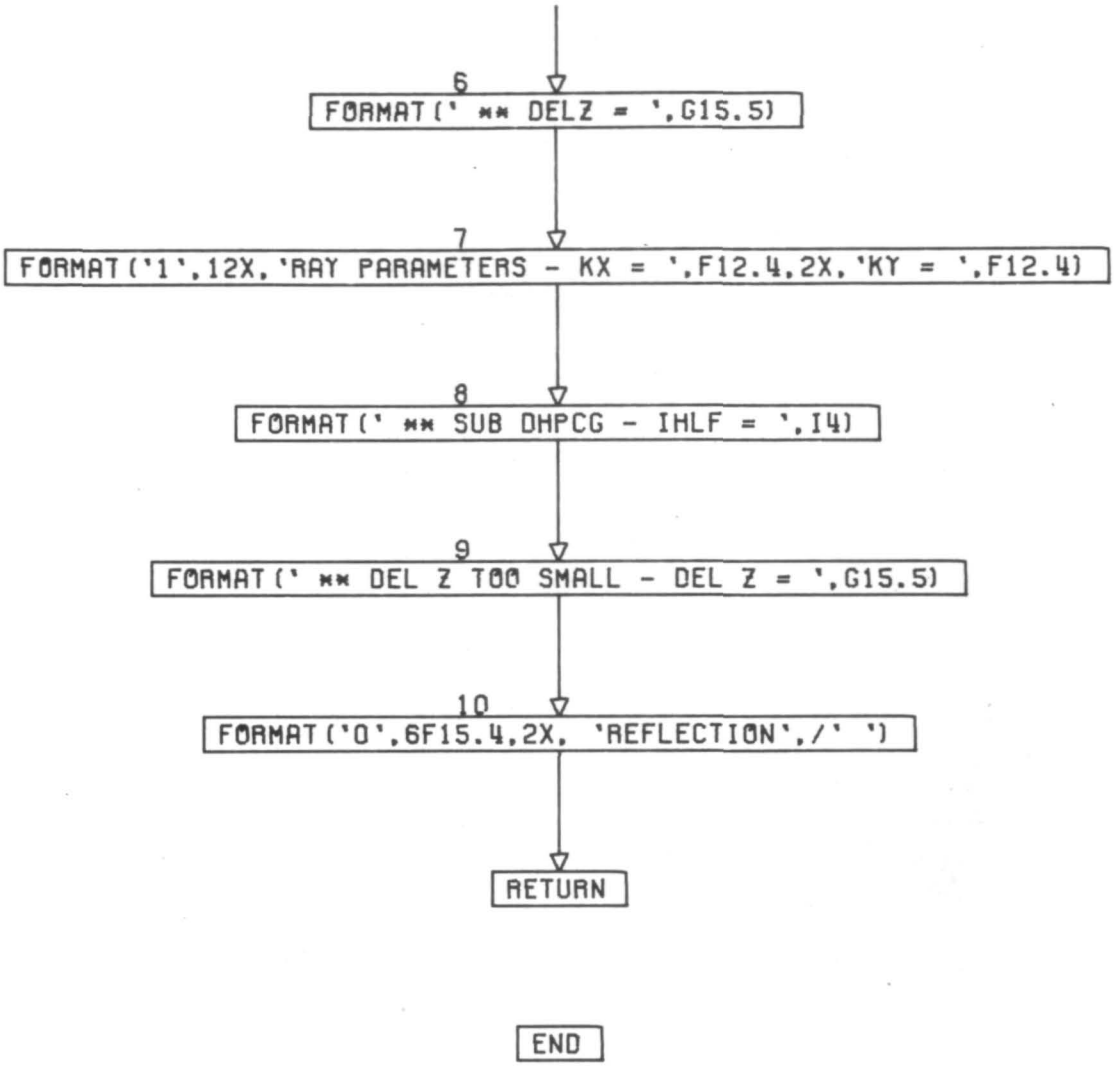
CONT. ON PG 8

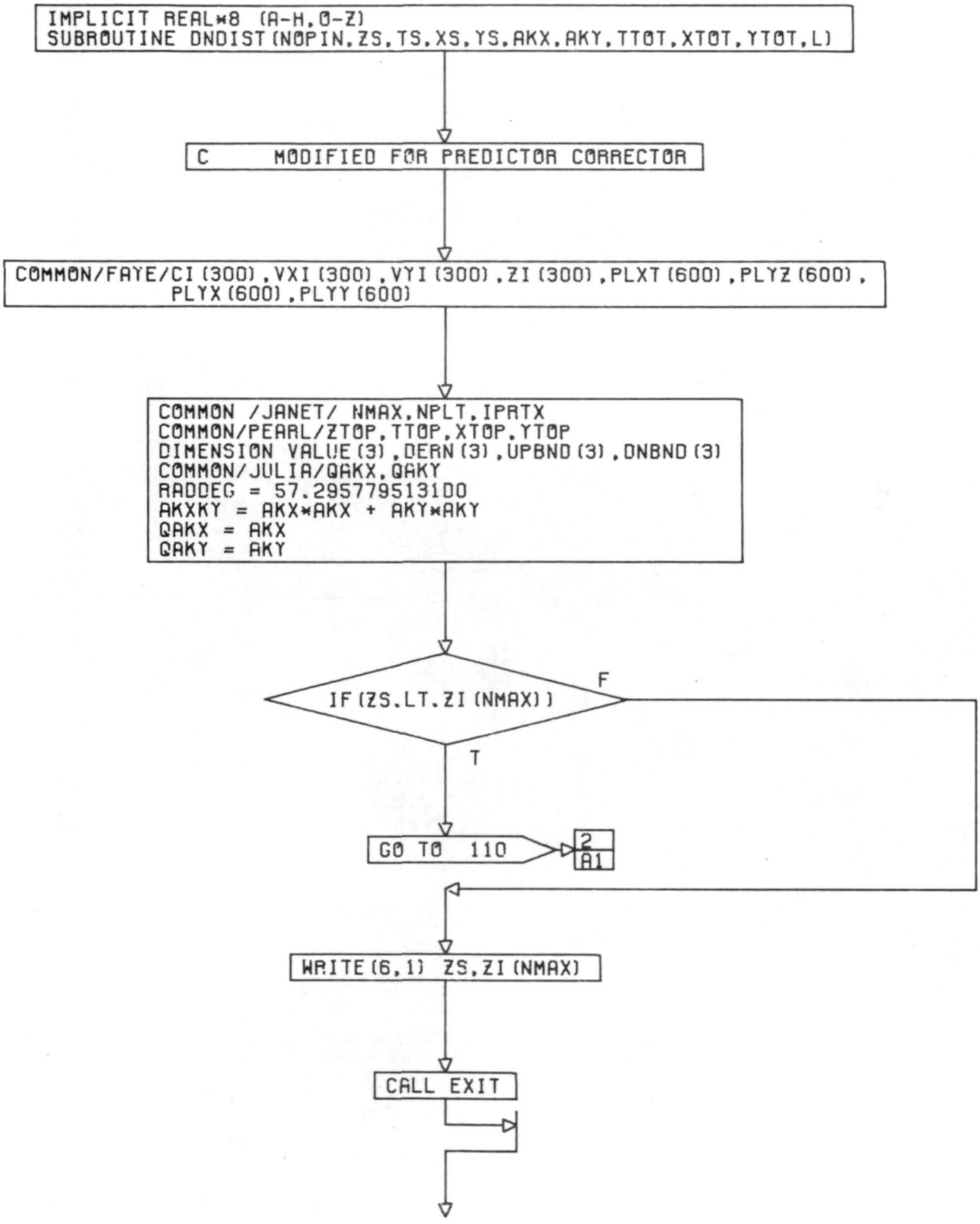

7
A7
WRITE(6,4) ZIND,VALUE,VT,WD,AK1SQ,AK2SQ
7
A8
AK1SQ = AK2SQ
5
160
CONTINUE
WRITE(6,5)
TTOT = VALUE(1)
XTOT = VALUE(2)
YTOT = VALUE(3)
L = -1
RETURN
6
A9
180
CONTINUE
CALL INTERP(AK1SQ,AK2SQ,ZI(I-1),ZI(I),AKX,AKY,VALUE)
TTOT = T2
XTOT = X2
YTOT = Y2
L=1
CALL ARTLU(2,ZTOP,ZI,VXTOP,VXI,VYTOP,VYI)

CONT. ON PG 9

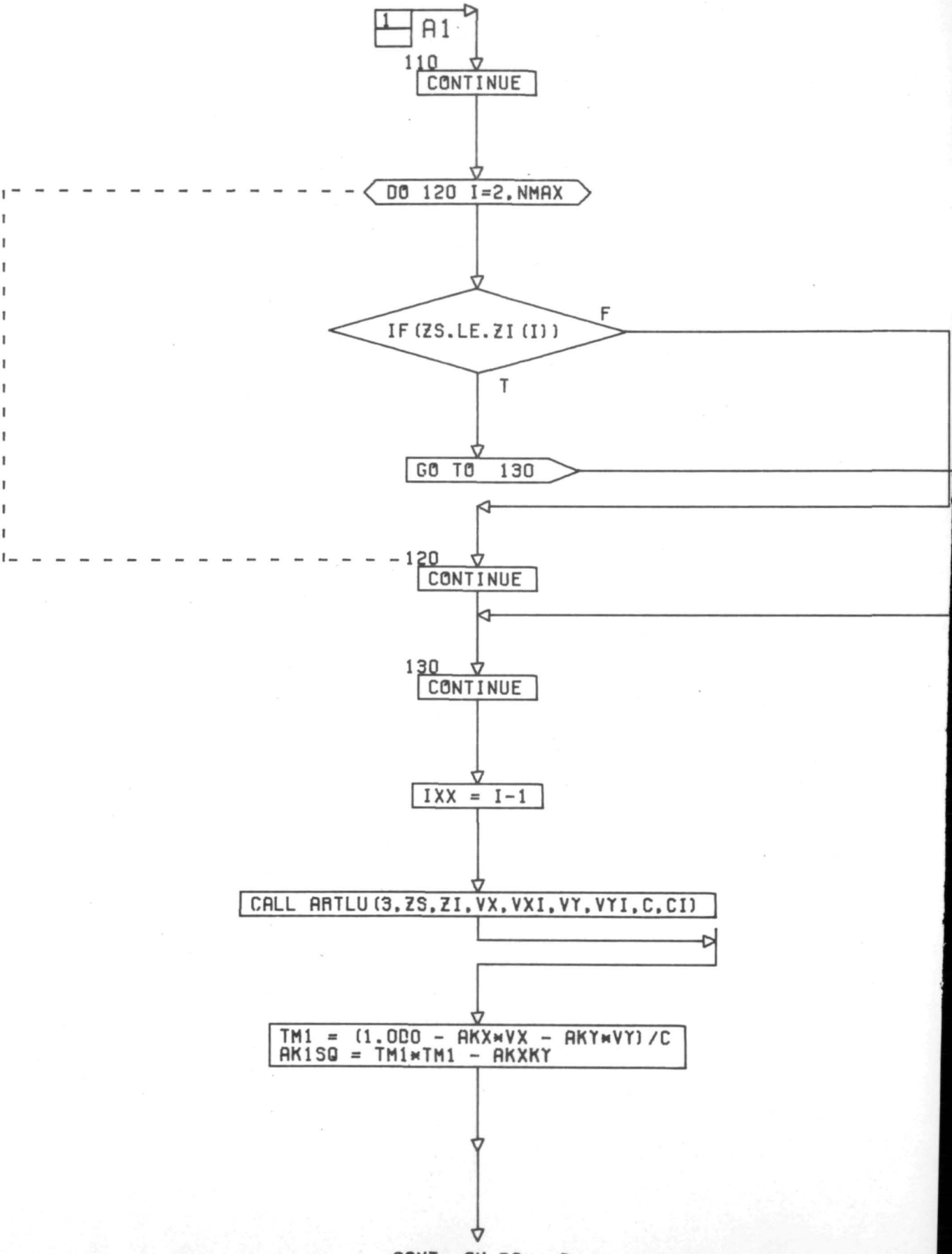

VT= DSQRT(VXTOP*VXTOP + VYTOP*VYTOP)
WD =0.000
VYVT = VY/VT
IF(VYVT.LT.1.000)
F
T
WD=DARCOS(VYVT)*RADDEG
WRITE(6,10) ZTOP,TTOP,XTOP,YTOP,VT,WD
1
FORMAT(' ** ZO = ',G15.5,2X,'ZMAX = ',G15.5)
2
FORMAT(' ** NO RAY AT ALTITUDE OF ',G15.5)
3
FORMAT('0',9X,'HEIGHT',11X,'TIME',10X,'XDIST',10X, 'YDIST',
11X,'VT',13X,'WD', 9X,'KZ1SQ',10X,'KZ2SQ',/' ')
4
FORMAT(' ',6F15.4,2G15.5)
5
FORMAT(' ** NOT ENOUGH DATA')

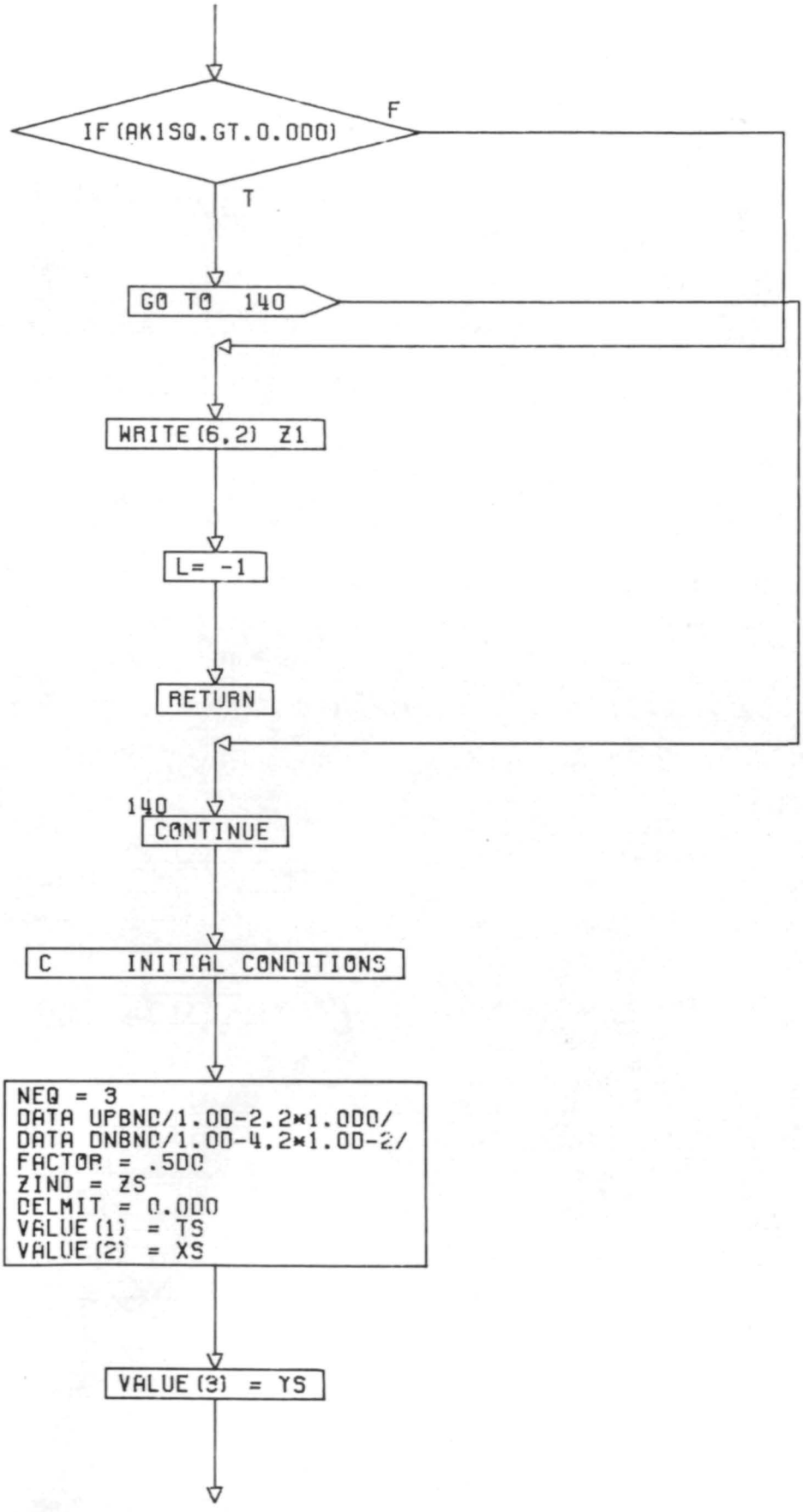
CONT. ON PG 10


6
FORMAT(' ** DELZ = ',G15.5)
7
FORMAT('1',12X,'RAY PARAMETERS - KX = ',F12.4,2X,'KY = ',F12.4)
8
FORMAT(' ** SUB DHPCG - IHLF = ',I4)
9
FORMAT(' ** DEL Z TOO SMALL - DEL Z = ',G15.5)
10
FORMAT('0',6F15.4,2X, 'REFLECTION',/' ')
RETURN
END

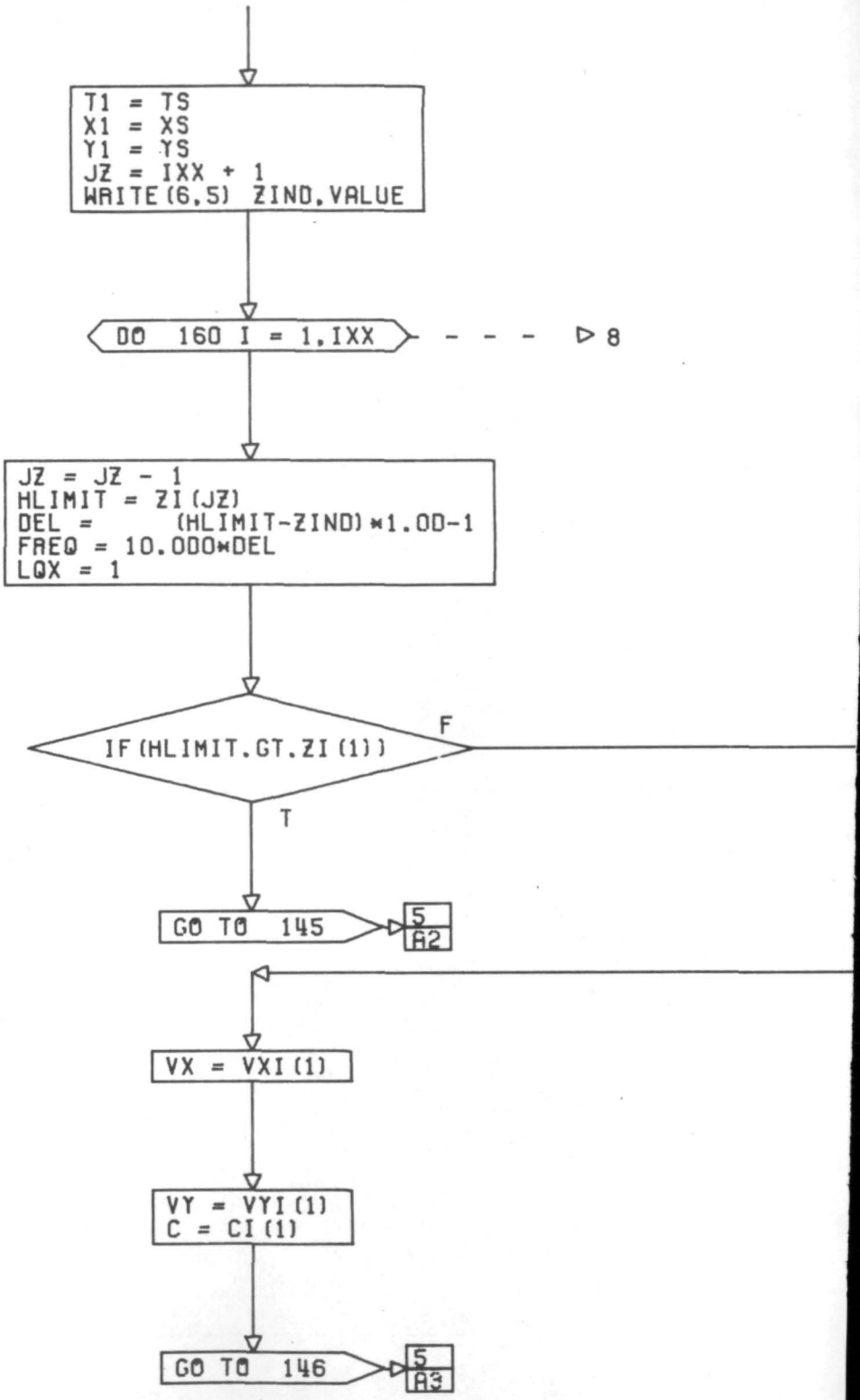

IMPLICIT REAL*8 (A-H,O-Z)
SUBROUTINE DNDIST(NOPIN,ZS,TS,XS,YS,AKX,AKY,TTOT,XTOT,YTOT,L)
C MODIFIED FOR PREDICTOR CORRECTOR
COMMON/FAYE/CI(300),VXI(300),VYI(300),ZI(300),PLXT(600),PLYZ(600),
PLYX(600),PLYY(600)
COMMON /JANET/ NMAX,NPLT,IPRTX
COMMON/PEARL/ZTOP,TTOP,XTOP,YTOP
DIMENSION VALUE(3),DERN(3),UPBND(3),DNBND(3)
COMMON/JULIA/QAKX,QAKY
RADDEG = 57.295779513100
AKXKY = AKX*AKX + AKY*AKY
QAKX = AKX
QAKY = AKY
IF(ZS.LT.ZI(NMAX))
F
T
GO TO 110
2
A1
WRITE(6,1) ZS,ZI(NMAX)
CALL EXIT

CONT. ON PG 2

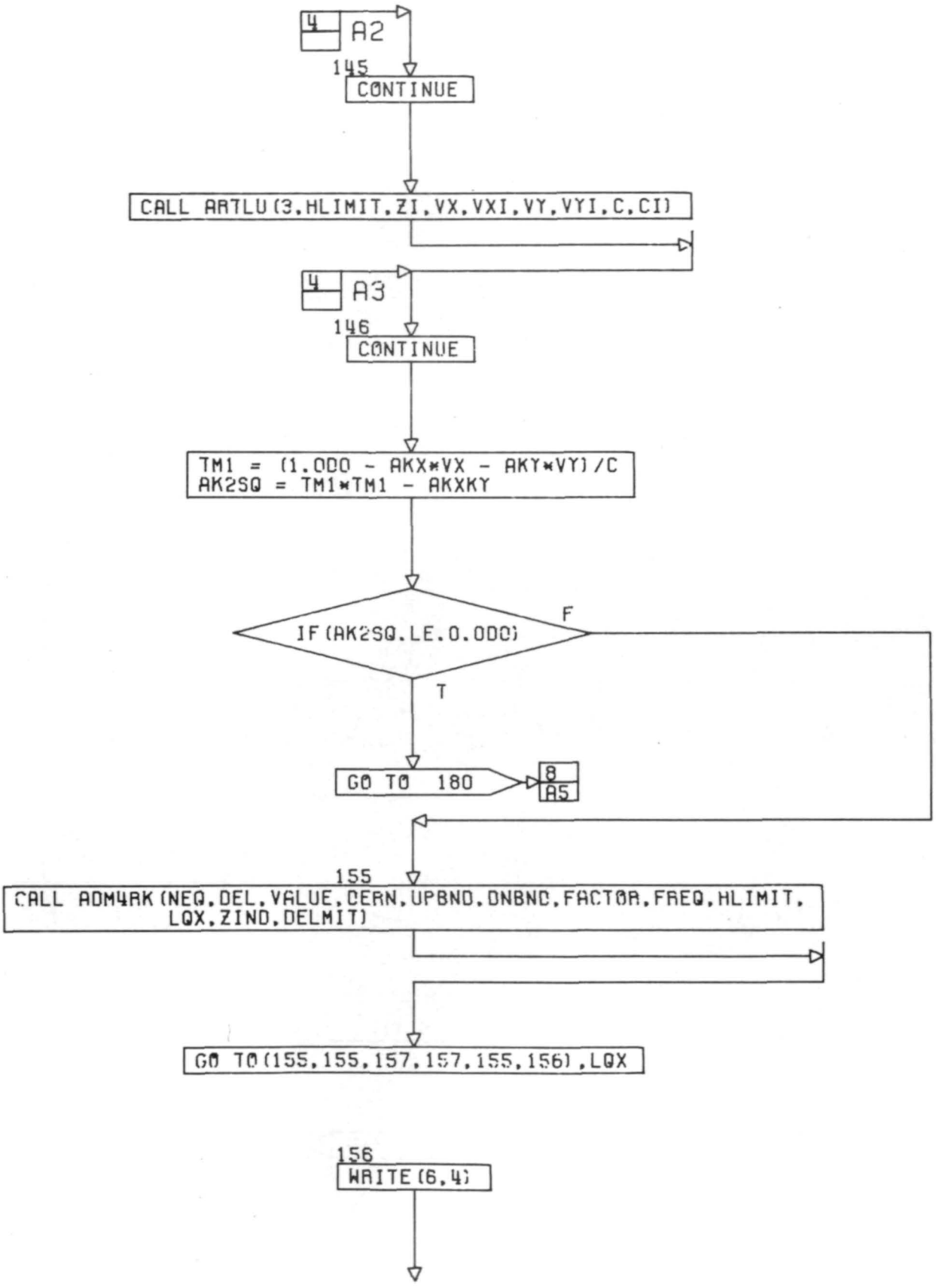

1
A1
110
CONTINUE
DO 120 I=2,NMAX
IF(ZS.LE.ZI(I))
F
T
GO TO 130
120
CONTINUE
130
CONTINUE
IXX = I-1
CALL ARTLU(3,ZS,ZI,VX,VXI,VY,VYI,C,CI)
TM1 = (1.0D0 - AKX*VX - AKY*VY)/C
AK1SQ = TM1*TM1 - AKXKY
CONT. ON PG 3


IF (AK1SQ.GT.0.0D0)
F
T
GO TO 140
WRITE(6,2) Z1
L= -1
RETURN
140
CONTINUE
C INITIAL CONDITIONS
NEQ = 3
DATA UPBND/1.0D-2,2*1.0D0/
DATA DNBND/1.0D-4,2*1.0D-2/
FACTOR = .5D0
ZIND = ZS
DELMIT = 0.0D0
VALUE(1) = TS
VALUE(2) = XS
VALUE(3) = YS

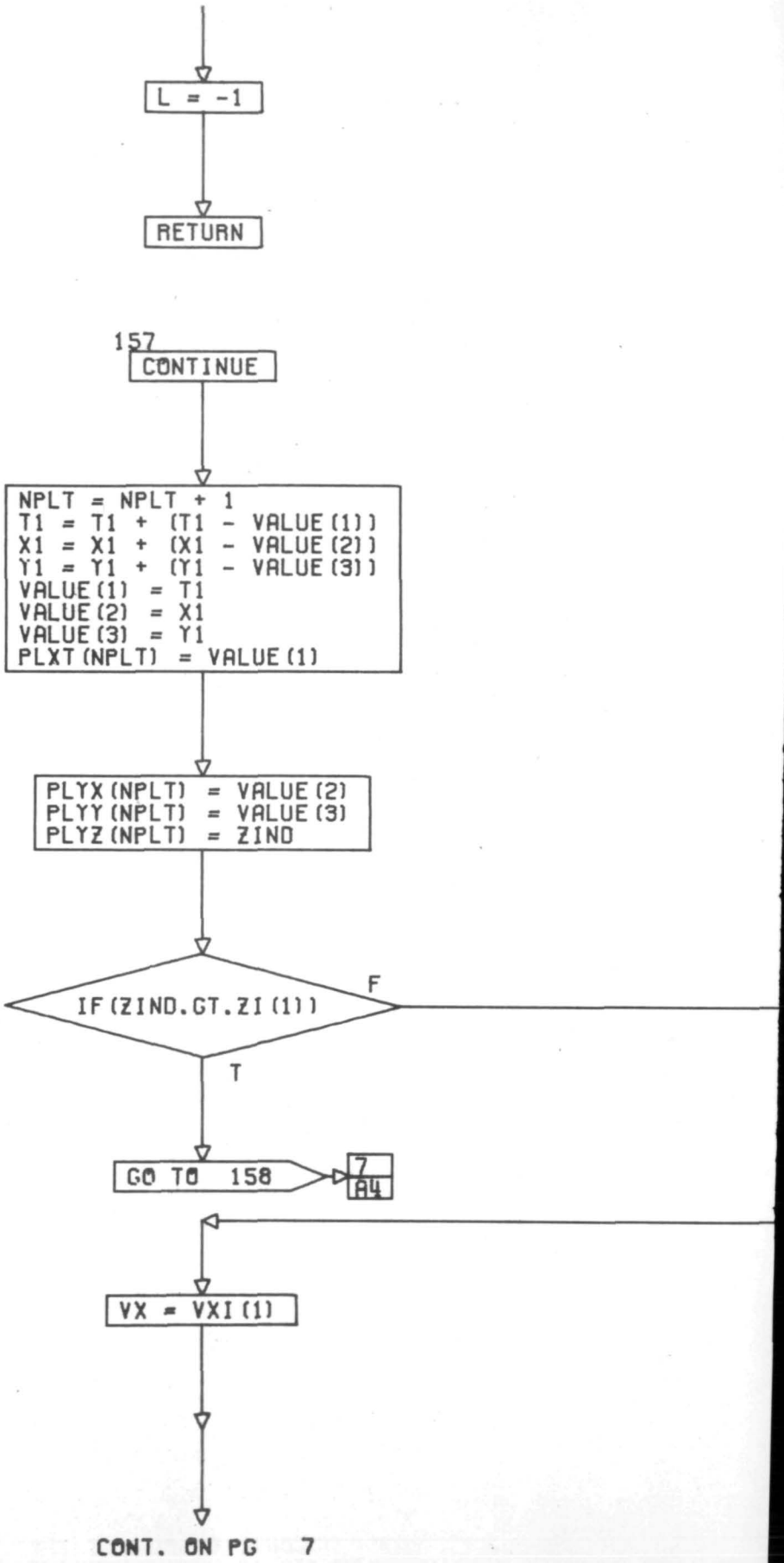
CONT. ON PG 4

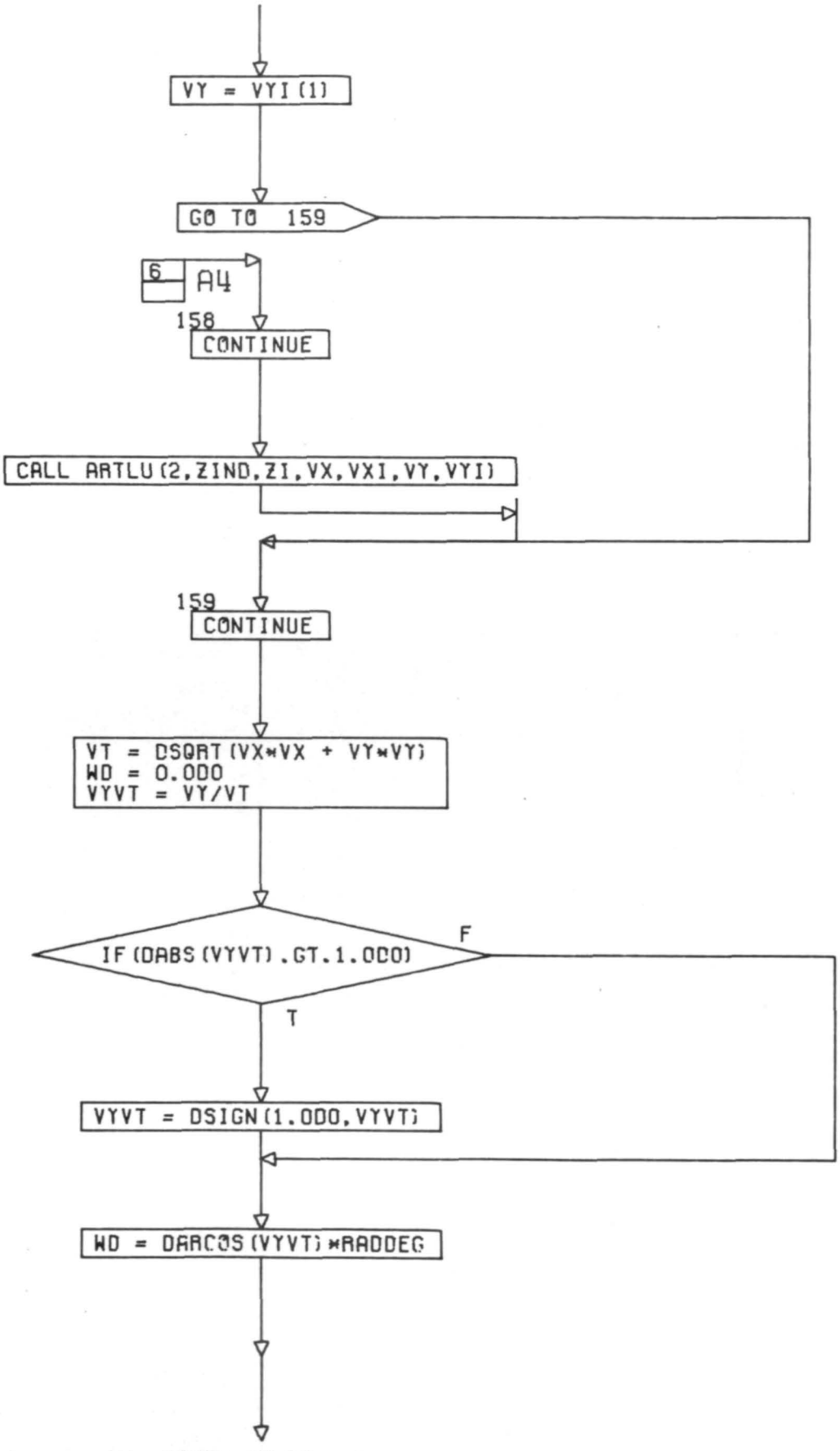

T1 = TS
X1 = XS
Y1 = YS
JZ = IXX + 1
WRITE(6,5) ZIND,VALUE
DO 160 I = 1,IXX
8
JZ = JZ - 1
HLIMIT = ZI(JZ)
DEL = (HLIMIT-ZIND)*1.0D-1
FREQ = 10.0D0**DEL
LQX = 1
IF(HLIMIT.GT.ZI(1))
F
T
GO TO 145
5
A2
VX = VXI(1)
VY = VYI(1)
C = CI(1)
GO TO 146
5
A3

CONT. ON PG 5

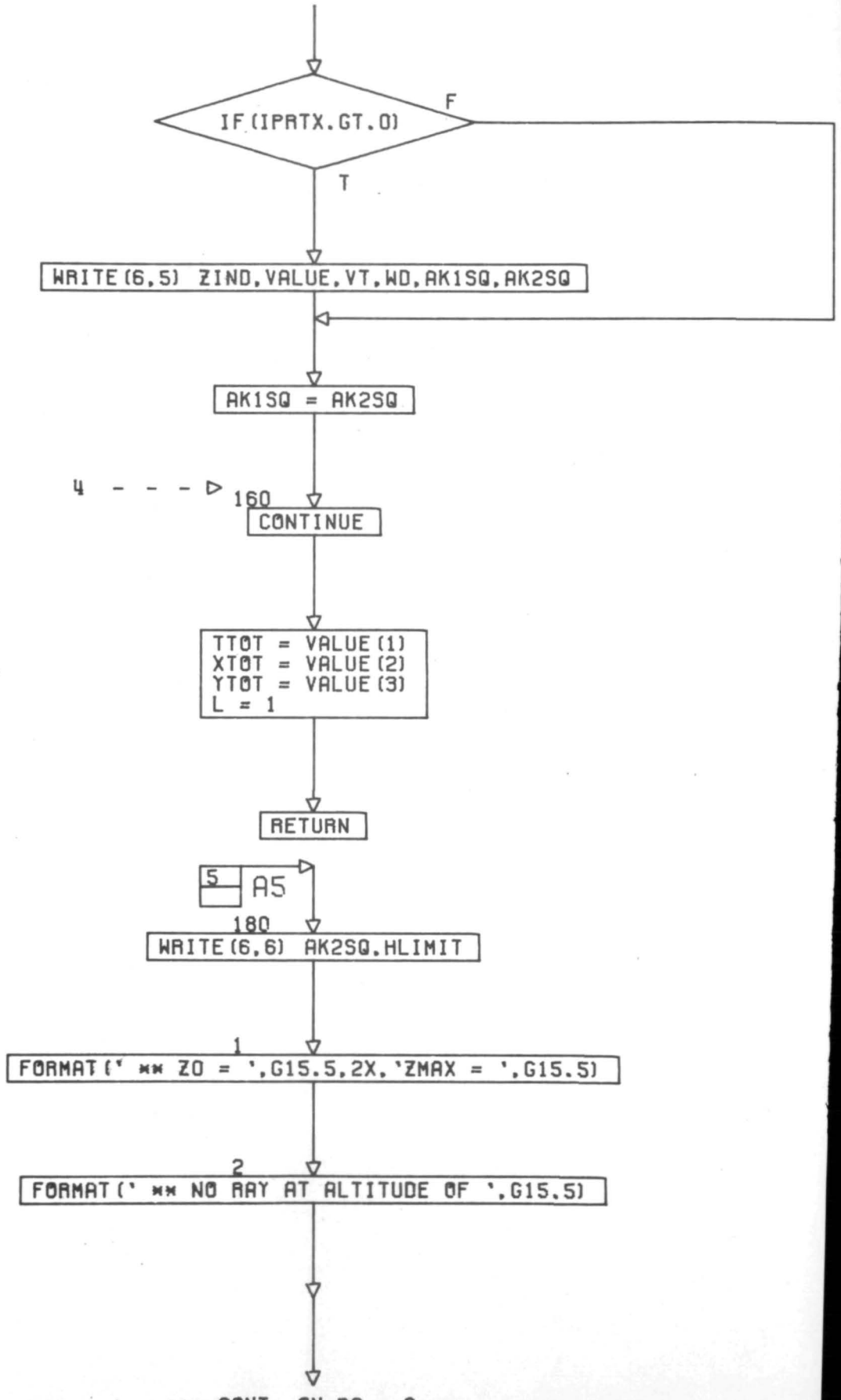

4
A2
145
CONTINUE
CALL ARTLU(3,HLIMIT,ZI,VX,VXI,VY,VYI,C,CI)
4
A3
146
CONTINUE
TM1 = (1.000 - AKX*VX - AKY*VY)/C
AK2SQ = TM1*TM1 - AKXKY
IF(AK2SQ.LE.0.000)
F
T
GO TO 180
8
A5
155
CALL ADM4RK(NEQ,DEL,VALUE,DERN,UPBND,DNBND,FACTOR,FREQ,HLIMIT,
LQX,ZIND,DELMIT)
GO TO(155,155,157,157,155,156),LQX
156
WRITE(6,4)

CONT. ON PG 6

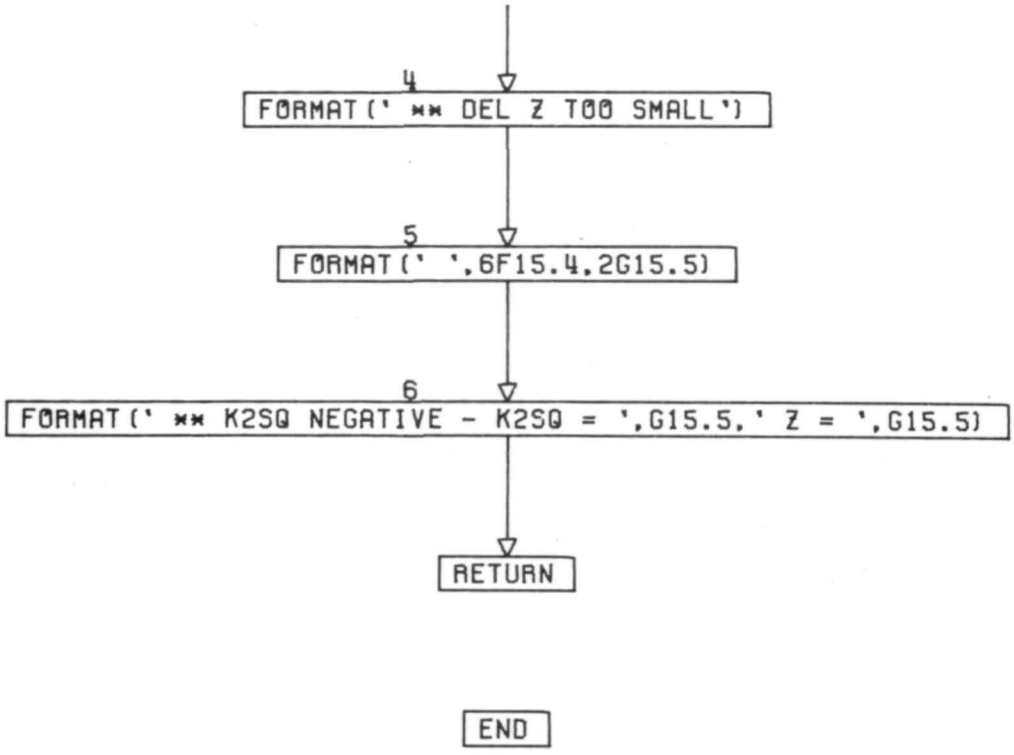

L = -1
RETURN
157
CONTINUE
NPLT = NPLT + 1
T1 = T1 + (T1 - VALUE(1))
X1 = X1 + (X1 - VALUE(2))
Y1 = Y1 + (Y1 - VALUE(3))
VALUE(1) = T1
VALUE(2) = X1
VALUE(3) = Y1
PLXT(NPLT) = VALUE(1)
PLYX(NPLT) = VALUE(2)
PLYY(NPLT) = VALUE(3)
PLYZ(NPLT) = ZIND
IF(ZIND.GT.ZI(1))
F
T
GO TO 158
7
A4
VX = VXI(1)
CONT. ON PG 7

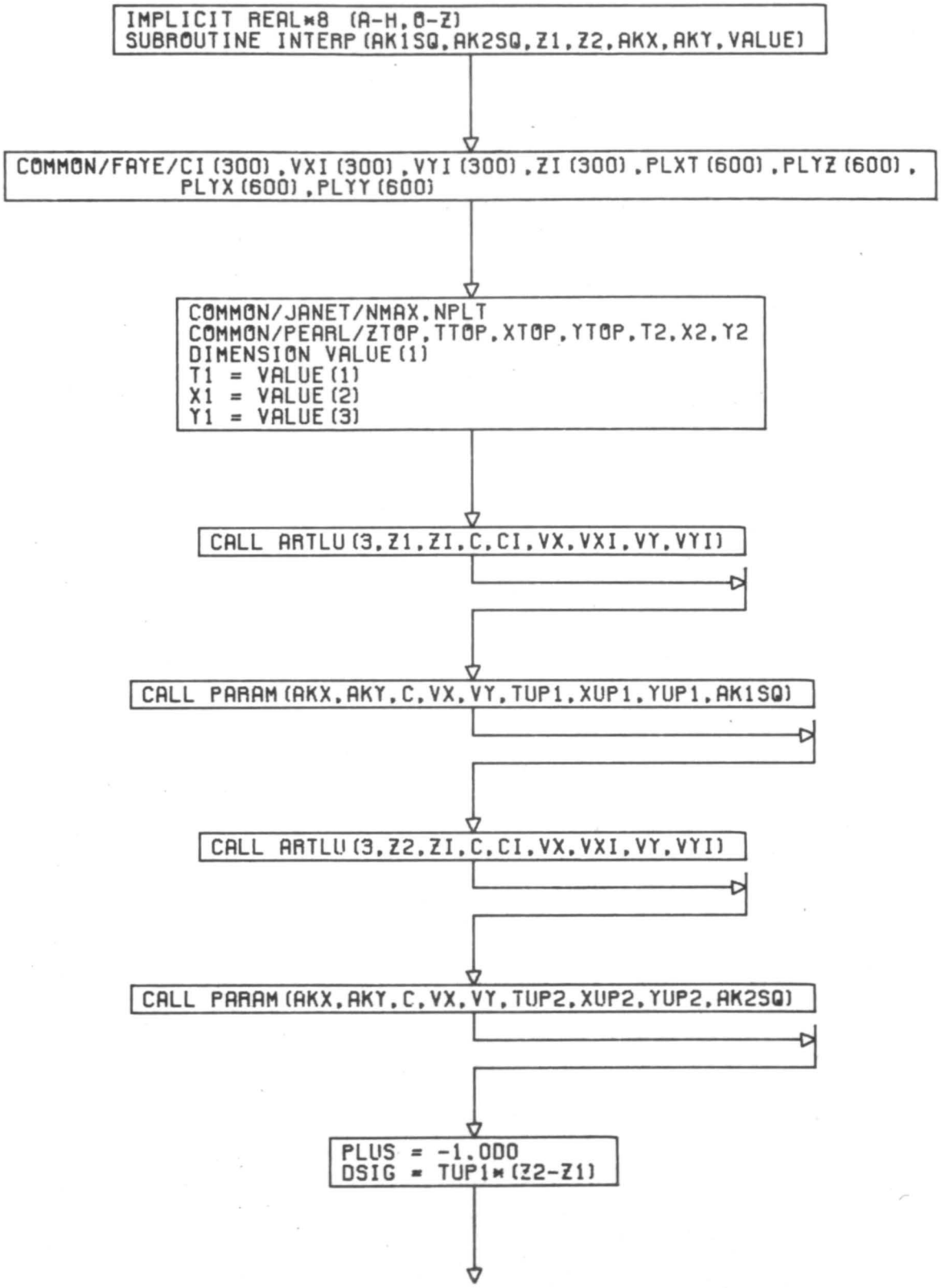

VY = VYI(1)
GO TO 159
6
A4
158
CONTINUE
CALL ARTLU(2,ZIND,ZI,VX,VXI,VY,VYI)
159
CONTINUE
VT = DSQRT(VX*VX + VY*VY)
WD = 0.0D0
VYVT = VY/VT
IF(DABS(VYVT).GT.1.0D0)
F
T
VYVT = DSIGN(1.0D0,VYVT)
WD = DARCOS(VYVT)*RADDEG

CONT. ON PG 8

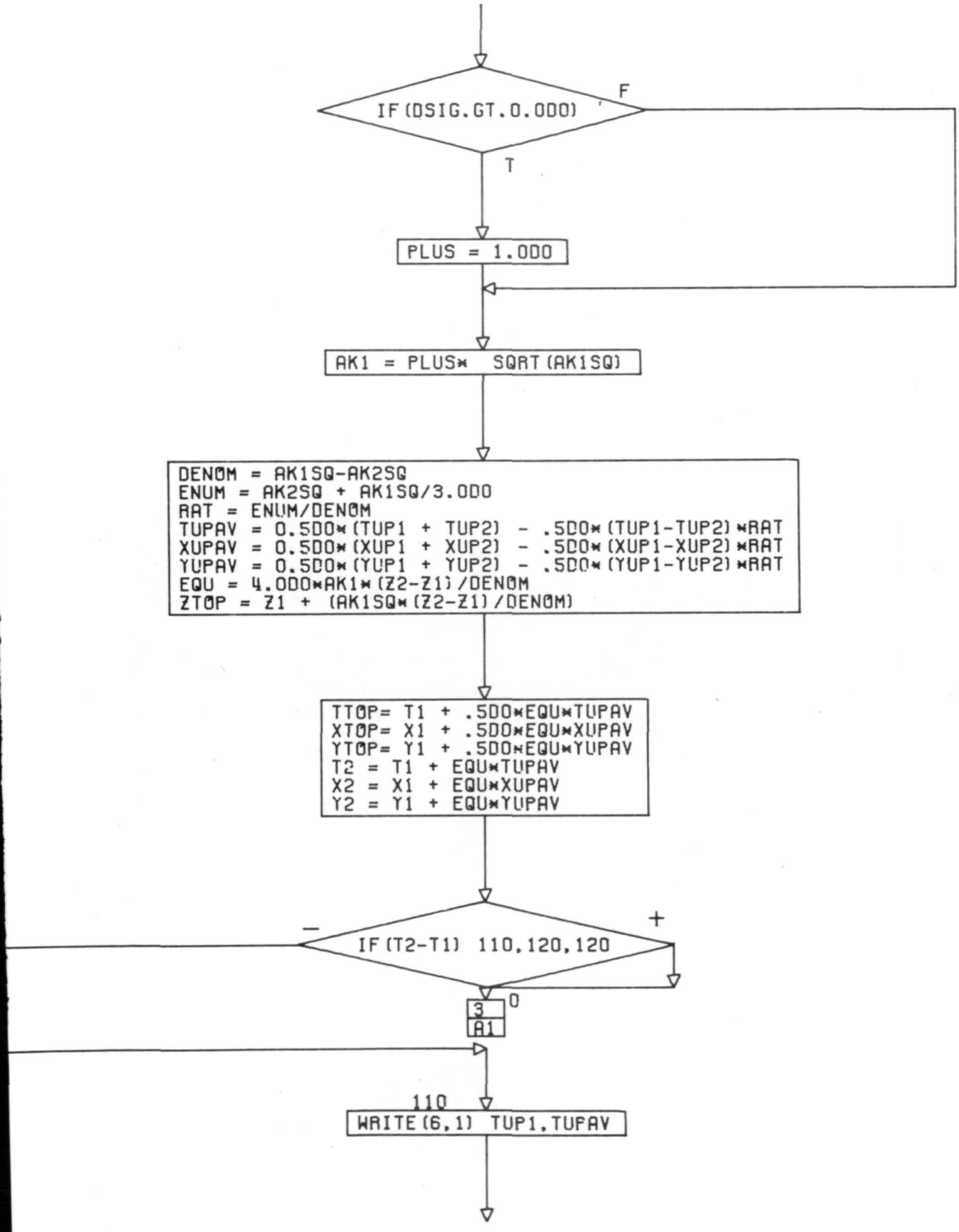

IF (IPRTX.GT.0)
F
T
WRITE(6,5) ZIND,VALUE,VT,WD,AK1SQ,AK2SQ
AK1SQ = AK2SQ
4
160
CONTINUE
TTOT = VALUE(1)
XTOT = VALUE(2)
YTOT = VALUE(3)
L = 1
RETURN
5
A5
180
WRITE(6,6) AK2SQ,HLIMIT
1
FORMAT(' ** ZO = ',G15.5,2X,'ZMAX = ',G15.5)
2
FORMAT(' ** NO RAY AT ALTITUDE OF ',G15.5)

CONT. ON PG 9

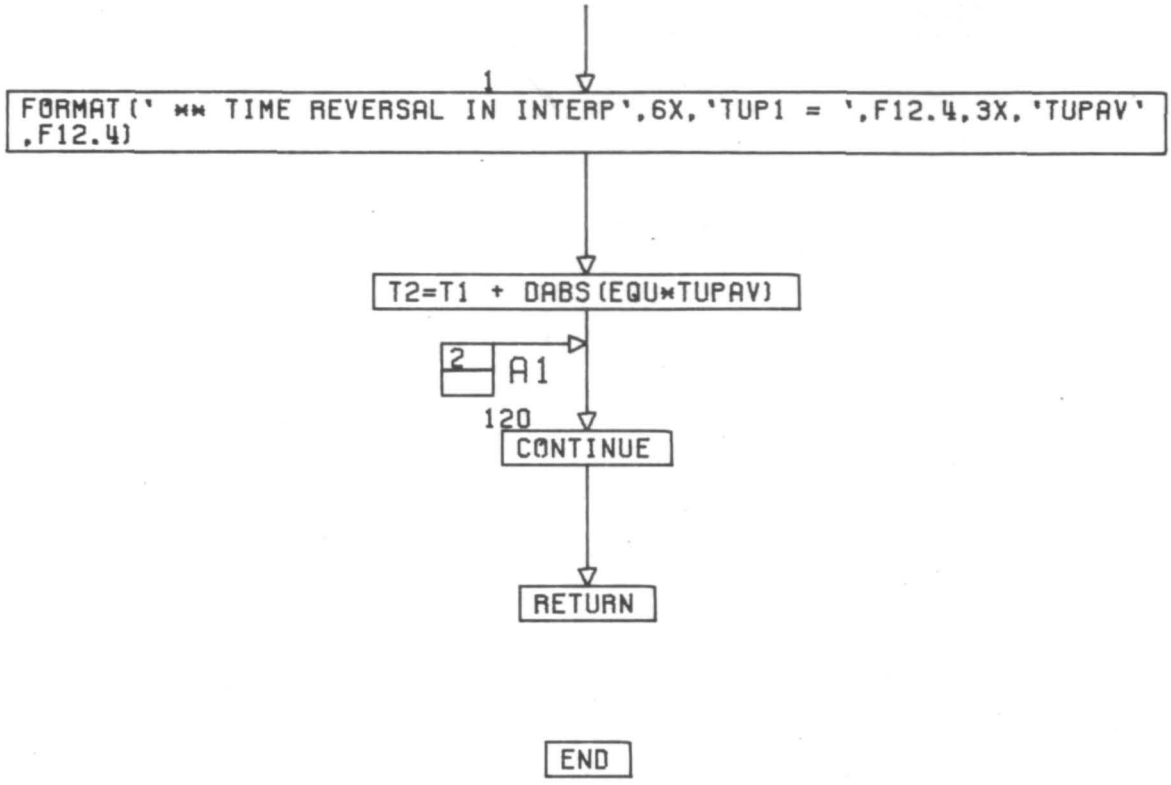

4
FORMAT(' ** DEL Z TOO SMALL')
5
FORMAT(' ',6F15.4,2G15.5)
6
FORMAT(' ** K2SQ NEGATIVE - K2SQ = ',G15.5,' Z = ',G15.5)
RETURN
END

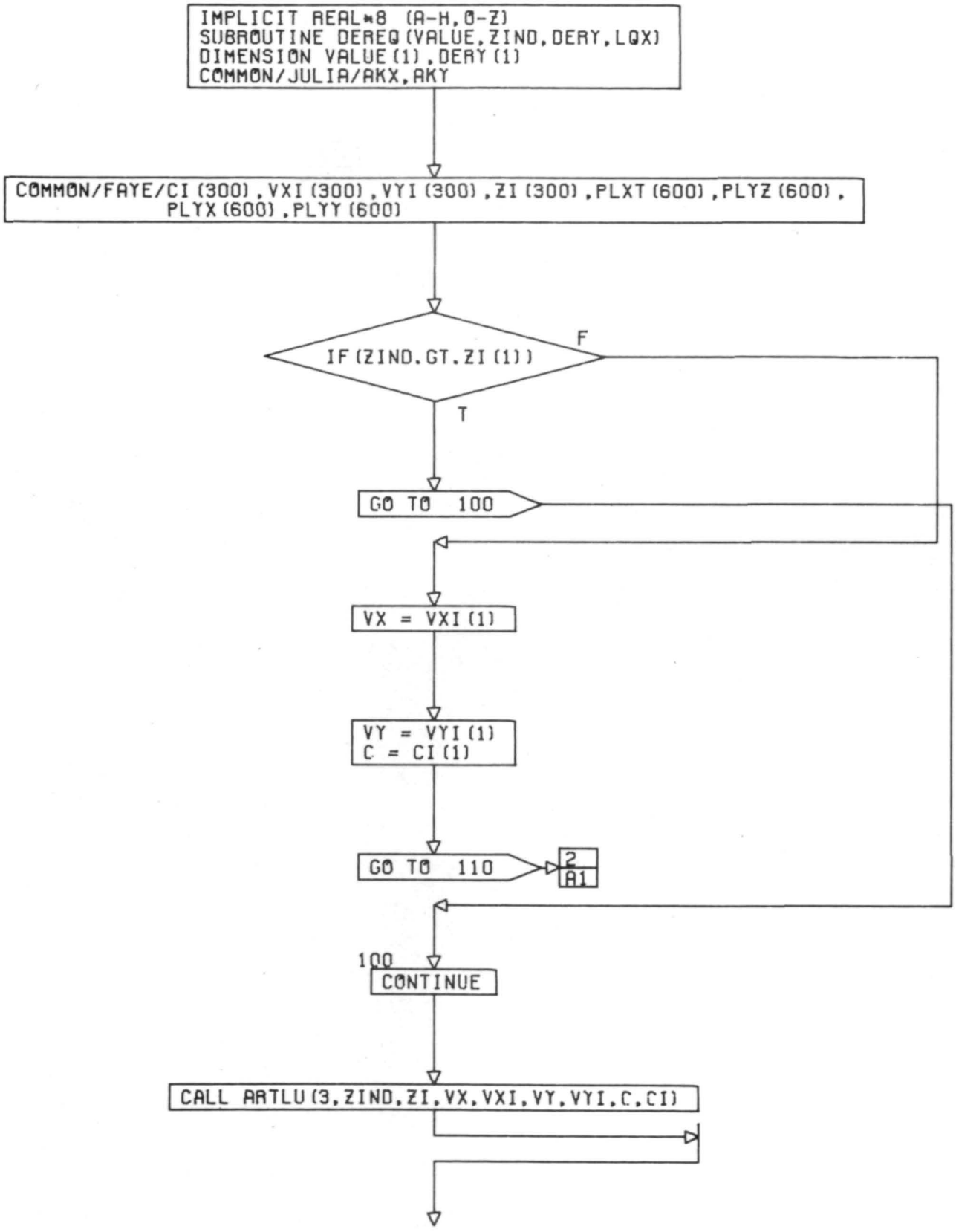

IMPLICIT REAL*8 (A-H,O-Z)
SUBROUTINE INTERP(AK1SQ,AK2SQ,Z1,Z2,AKX,AKY,VALUE)
COMMON/FAYE/CI(300),VXI(300),VYI(300),ZI(300),PLXT(600),PLYZ(600),
PLYX(600),PLYY(600)
COMMON/JANET/NMAX,NPLT
COMMON/PEARL/ZTOP,TTOP,XTOP,YTOP,T2,X2,Y2
DIMENSION VALUE(1)
T1 = VALUE(1)
X1 = VALUE(2)
Y1 = VALUE(3)
CALL ARTLU(3,Z1,ZI,C,CI,VX,VXI,VY,VYI)
CALL PARAM(AKX,AKY,C,VX,VY,TUP1,XUP1,YUP1,AK1SQ)
CALL ARTLU(3,Z2,ZI,C,CI,VX,VXI,VY,VYI)
CALL PARAM(AKX,AKY,C,VX,VY,TUP2,XUP2,YUP2,AK2SQ)
PLUS = -1.0D0
DSIG = TUP1*(Z2-Z1)

CONT. ON PG 2

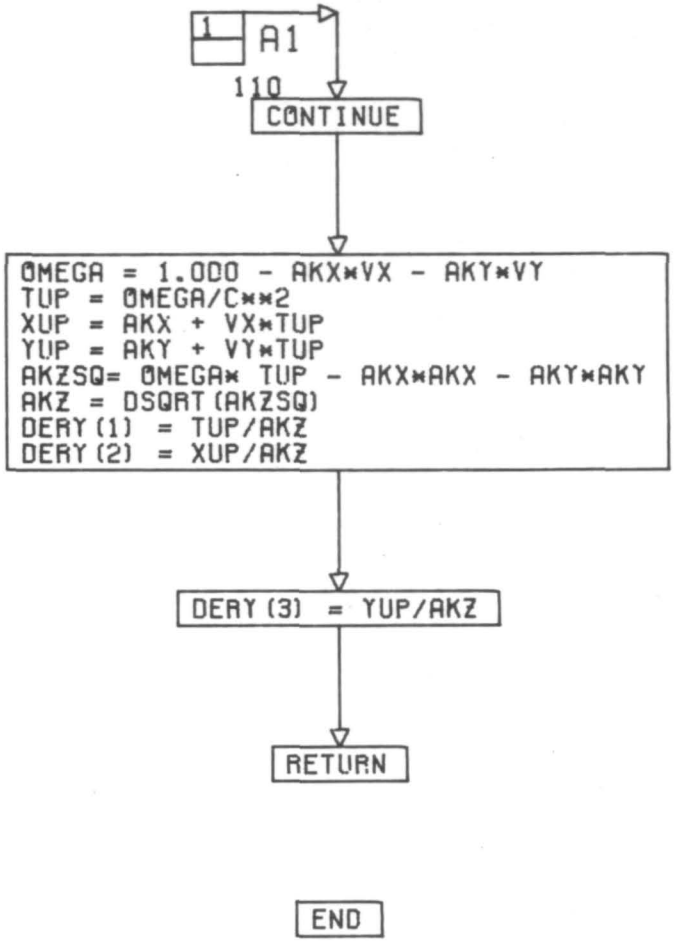

IF(DSIG.GT.0.000)
F
T
PLUS = 1.000
AK1 = PLUS* SQRT(AK1SQ)
DENOM = AK1SQ-AK2SQ
ENUM = AK2SQ + AK1SQ/3.000
RAT = ENUM/DENOM
TUPAV = 0.500*(TUP1 + TUP2) - .500*(TUP1-TUP2)*RAT
XUPAV = 0.500*(XUP1 + XUP2) - .500*(XUP1-XUP2)*RAT
YUPAV = 0.500*(YUP1 + YUP2) - .500*(YUP1-YUP2)*RAT
EQU = 4.000*AK1*(Z2-Z1)/DENOM
ZTOP = Z1 + (AK1SQ*(Z2-Z1)/DENOM)
TTOP= T1 + .500*EQU*TUPAV
XTOP= X1 + .500*EQU*XUPAV
YTOP= Y1 + .500*EQU*YUPAV
T2 = T1 + EQU*TUPAV
X2 = X1 + EQU*XUPAV
Y2 = Y1 + EQU*YUPAV
IF(T2-T1) 110,120,120
-
+
0
3
A1
110
WRITE(6,1) TUP1,TUPAV

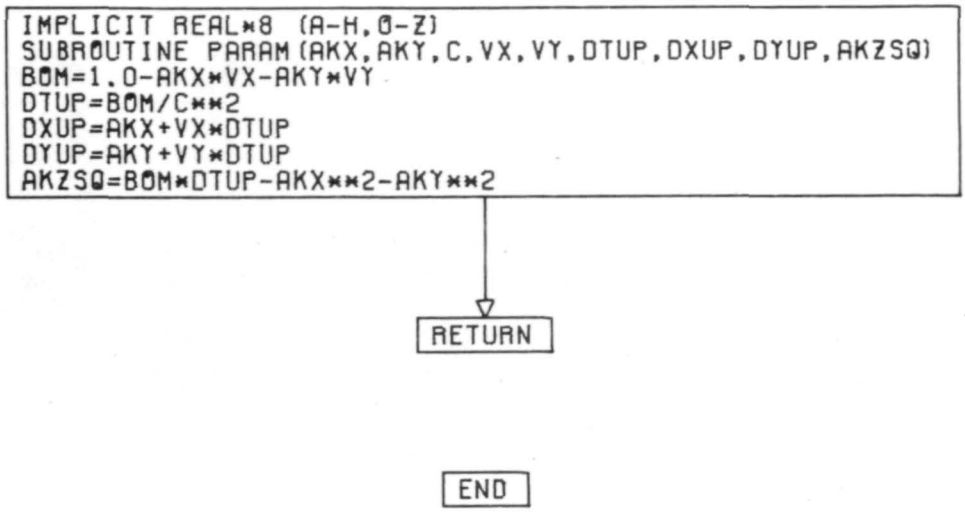
CONT. ON PG 3


1
FORMAT(' ** TIME REVERSAL IN INTERP',6X,'TUP1 = ',F12.4,3X,'TUPAV'
,F12.4)
T2=T1 + DABS(EQU*TUPAV)
2
A1
120
CONTINUE
RETURN
END


IMPLICIT REAL*8 (A-H,0-Z)
SUBROUTINE DEREQ(VALUE,ZIND,DERY,LQX)
DIMENSION VALUE(1),DERY(1)
COMMON/JULIA/AKX,AKY
COMMON/FAYE/CI(300),VXI(300),VYI(300),ZI(300),PLXT(600),PLYZ(600),
PLYX(600),PLYY(600)
IF(ZIND.GT.ZI(1))
F
T
GO TO 100
VX = VXI(1)
VY = VYI(1)
C = CI(1)
GO TO 110
2
A1
100
CONTINUE
CALL ARTLU(3,ZIND,ZI,VX,VXI,VY,VYI,C,CI)

CONT. ON PG 2


1
A1
110
CONTINUE
OMEGA = 1.000 - AKX*VX - AKY*VY
TUP = OMEGA/C**2
XUP = AKX + VX*TUP
YUP = AKY + VY*TUP
AKZSQ= OMEGA* TUP - AKX*AKX - AKY*AKY
AKZ = DSQRT(AKZSQ)
DERY(1) = TUP/AKZ
DERY(2) = XUP/AKZ
DERY(3) = YUP/AKZ
RETURN
END


IMPLICIT REAL*8 (A-H,0-Z)
SUBROUTINE PARAM(AKX,AKY,C,VX,VY,DTUP,DXUP,DYUP,AKZSQ)
BOM=1.0-AKX*VX-AKY*VY
DTUP=BOM/C**2
DXUP=AKX+VX*DTUP
DYUP=AKY+VY*DTUP
AKZSQ=BOM*DTUP-AKX**2-AKY**2
RETURN
END