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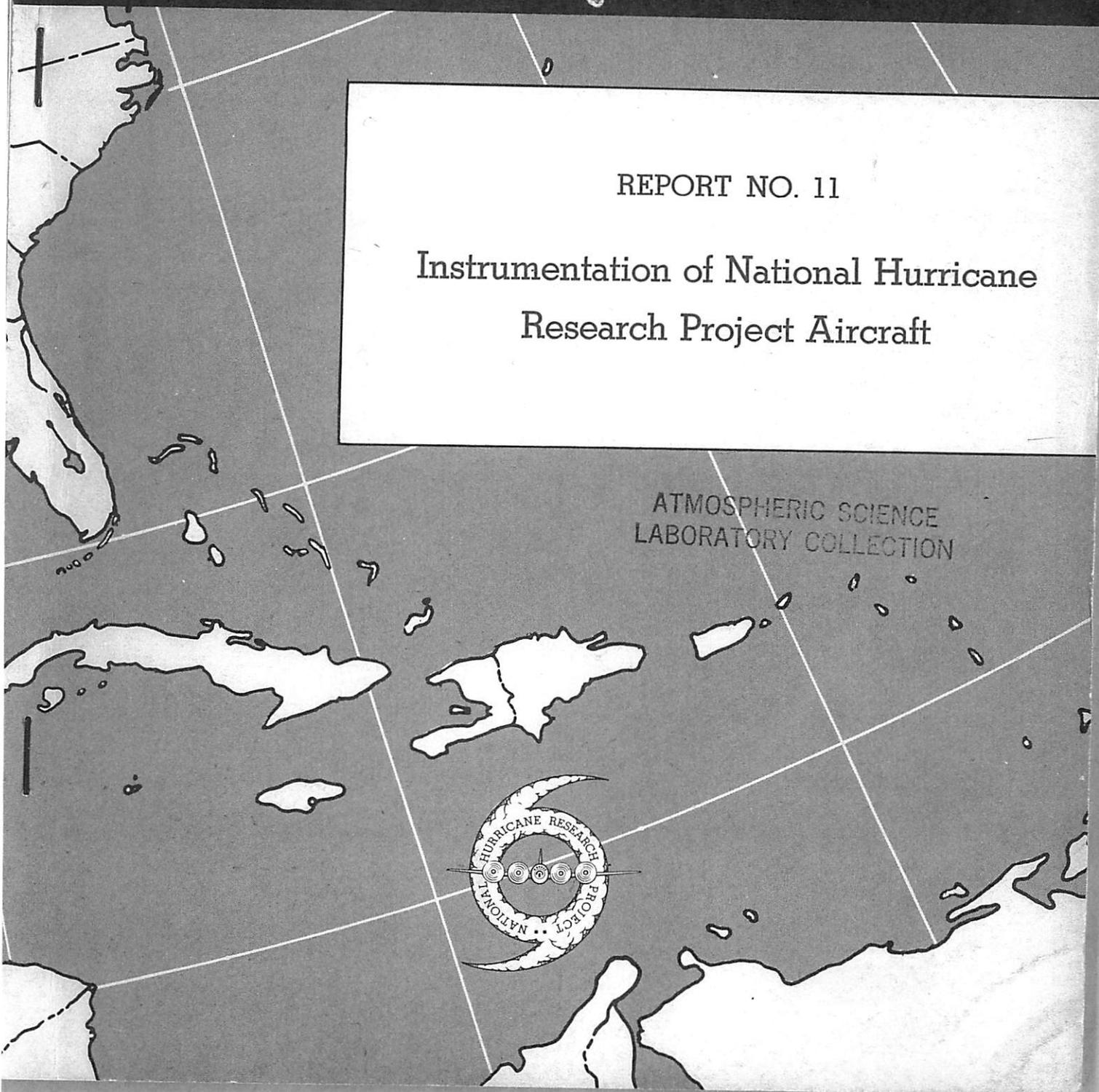
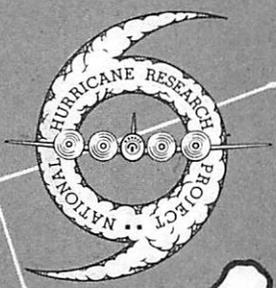
NATIONAL HURRICANE RESEARCH PROJECT

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REPORT NO. 11

Instrumentation of National Hurricane Research Project Aircraft

ATMOSPHERIC SCIENCE
LABORATORY COLLECTION



U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, Secretary
WEATHER BUREAU
F. W. Reichelderfer, Chief

NATIONAL HURRICANE RESEARCH PROJECT

REPORT NO. 11

Instrumentation of National Hurricane
Research Project Aircraft

by

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Research Operations Base

National Hurricane Research Project, West Palm Beach, Fla.



ATMOSPHERIC SCIENCE
LABORATORY COLLECTION

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NATIONAL HURRICANE RESEARCH PROJECT REPORTS

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- No. 11. Instrumentation of National Hurricane Research Project aircraft. August 1957.

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INSTRUMENTATION OF NATIONAL HURRICANE RESEARCH PROJECT AIRCRAFT

[Manuscript received April 9, 1957]

INTRODUCTION

This paper describes the various instrumentation systems installed on the three aircraft assigned to the National Hurricane Research Project. Explanations of the several systems and reasons for the different methods of recording are given. The paper also describes the calibration work performed to date, together with estimates of the reliability of the particular instruments, based upon the rather brief period of operation during 1956, or upon statements by the manufacturers. This report will be supplemented later with information concerning further development of the instrumentation systems and additional calibration work, which will be done as time permits, to estimate more exactly the reliability of the systems.

The National Hurricane Research Project used the services of its Advisory Panel on Instrumentation to review and revise the first instrumentation proposals. Participants in the Panel were:

L. M. Allison, National Bureau of Standards
John C. Bellamy, Cook Research Laboratories
J. L. Dennis, General Precision Laboratory, Inc.
R. C. Gentry, U. S. Weather Bureau
Maurice L. Greenough, National Bureau of Standards
Ross Gunn, U. S. Weather Bureau
Lt. Col. George A. Guy, U. S. Air Force, Air Research and Development Command, Baltimore, Md.
William Hakkarinen, National Bureau of Standards
Ferguson Hall, U. S. Weather Bureau
Christos Harmantas, U. S. Weather Bureau
L. F. Hubert, U. S. Weather Bureau
Claude A. Kettering, U. S. Weather Bureau
N. E. LaSeur, Florida State University
H. J. Mastenbrook, Naval Research Laboratory
W. A. Maxim, Wright Air Development Center, Wright Patterson Air Force Base
R. M. Rados, Geophysics Research Directorate, Air Force Cambridge Research Center
Herbert Riehl, University of Chicago
Vaughn D. Rockney, U. S. Weather Bureau
R. E. Ruskin, Naval Research Laboratory
S. Shefter, U. S. Army Signal Corps
R. H. Simpson, U. S. Weather Bureau
V. E. Suomi, University of Wisconsin
Arnold Wexler, National Bureau of Standards
Rex C. Wood, U. S. Weather Bureau
A. W. Youmans, U. S. Weather Bureau

In addition, the following organizations have contributed instrumentation and advice for particular portions of the instrumentation scheme: Wright Air Development Center, University of Dayton, National Advisory Committee for Aeronautics (through its Langley Field and Lewis Aeronautical Laboratories), University of Chicago, and the Weather Bureau Instrumental Engineering Division. Dr. W. Richardson and Dr. W. S. Von Arx of Woods Hole Oceanographic Institution provided the sea surface temperature-measuring equipment and the cloud cameras, respectively.

While the systems were being developed and installed, Mr. Robert M. Rados of the Geophysical Research Directorate, U. S. Air Force Cambridge Research Center, was on the staff of the Hurricane Project and contributed materially to the technical installation.

The portion of the paper which describes cloud physics instrumentation is drawn from information supplied by Dr. Roscoe Braham of the Department of Meteorology, University of Chicago. The University of Chicago staff is largely responsible for the development of the cloud physics system used.

Most of the installation work was performed under contract with General Precision Laboratory, Inc. This organization provided much of the engineering design for the instrumentation scheme and, in particular, developed the electronic digital recording system and the automatic navigation equipment.

In the support of the flying program, personnel of Palm Beach Air Force Base and, in particular, of the 1707th Field Maintenance Squadron, were helpful in insuring the proper installation and functioning of the various items of equipment. Unusual efforts were made to complete missions at times of meteorological importance, which could not have been accomplished if it were not for the perseverance of Base personnel.

The Project is indebted to all of the above-mentioned persons and agencies for their significant contributions to the success of the aircraft installation, the planning of which was not participated in by the authors of this description.

I. DESCRIPTION OF THE NATIONAL HURRICANE RESEARCH PROJECT AIRCRAFT INSTRUMENTATION

The National Hurricane Research Project utilizes three specially instrumented U. S. Air Force airplanes, operated and maintained by the Air Weather Service. Two are TB-50A's, four-engine conventional aircraft comparable in performance to the WB-50's used by the Air Weather Service. The third plane is a B-47B, a turbojet powered aircraft. These planes were built by the Boeing Airplane Company.

The instrumentation system was selected with three operational purposes in mind. The primary purpose of the aircraft is to make reconnaissance flights into all portions of hurricanes. Those instruments normally used on weather reconnaissance aircraft were deemed the most suitable means for obtaining most of the measurements desired. An IBM card digital recording method was chosen

to record most of these measurements. The digital recording system used allows quick preliminary evaluation of the data after the aircraft return.

The aircraft are also used for a program of research flights into regions of possible hurricane formation and into other areas occupied by tropical weather situations of particular interest. In addition to the standard instrumentation, certain special and, in some cases, experimental equipment has been installed in the aircraft to permit measurement of meteorological and oceanographic information not normally obtained by routine reconnaissance flights. The special instrument signals are recorded by several methods. Nearly all are presented on an instrument photo panel which is photographed by a recording camera, and was intended as a backup recording method designed to record most of the regular and special instrument signals.

The third use of the TB-50 aircraft is in the field of cloud physics research. The Cloud Physics Project of the University of Chicago has provided cloud physics instrumentation and is participating in the NHRP flight program in order to make an investigation of tropical and hurricane clouds. The cloud physics equipment was installed on only one of the TB-50's during the 1956 flight program because of lack of time. Oscillographs are used to record the fast-changing cloud physics parameters.

Wright Air Development Center and the National Advisory Committee for Aeronautics have also contributed instrument systems to the Project aircraft, and use has been made wherever possible of the standard instruments supplied with the planes.

The installation of the instruments in the three aircraft was performed by General Precision Laboratory, Inc., which also designed and constructed the digital recording system, the photo panel, and the instrumentation power system, and supplied the AN/APN-82 radio navigation system.

One of the important features of the instrument system is the employment of a master timing unit which serves to coordinate nearly all of the records. This coordination is supplemented by a data-counting system which counts the IBM cards and photo panel pictures which are always made simultaneously.

Another feature of the system is the centralization of most of the instrument power and adjustment controls at a single flight technician's position in the aircraft, which leaves the meteorologist and cloud physicist free for other duties. The IBM card punch, master control panel, oscillograph, and most of the instrument controls, are located near the flight technician in the waist of the aircraft. This arrangement places great responsibility on the flight technician but allows him to coordinate the instrumentation effectively.

The most significant feature of the system is the digital recording method. The flexibility of the digital system, particularly the ease of changing the data-sampling rate, together with the wide range of rates possible, is very advantageous in meteorological research. The photo panel recording system has this same advantage but its data are not immediately available for analysis. The IBM card method eliminates the slow process of reading film or chart records. Moreover, it presents data for each record point in a form that permits optimum flexibility in processing, plotting out, and applying various corrections for recorded values.

Table 1 and figures 1 and 2 present in outline and diagram form the NHRP aircraft instrumentation systems. The items in the table marked with an asterisk are not included in the B-47 instrumentation system.

Table 1. - NHRP aircraft instrumentation system.

Information	Instrument	Recorders	Substitute
Data sequence identification	Digital system	Digital, photo panel flight log	Timer
Time	Master timer	All recorders except pen recorder	Clocks
Latitude and Longitude	AN/APN-82	Digital, photo panel, Flight log	Dead reckoning, radar fixes, Loran, etc.
Ground speed	AN/APN-82	Photo panel, flight log	Dead reckoning, radar fixes, Loran, etc.
Drift angle	AN/APN-82	Photo panel, flight log	Drift sight
Compass heading	N-1 compass system	Photo panel, flight log	None
Indicated airspeed	I.A.S. transducer system and I.A.S. meters	Oscillograph, Photo panel	None
True airspeed	AN/APN-82 and T.A.S. meters	Photo panel, flight log	None
Flight/run identifier	Master control panel	Digital, photo panel, flight log	Labeled plaque in photo panel
Wind direction and speed	AN/APN-82	Digital, photo panel, flight log	Comp. from ground speed, drift angle, T.A.S. heading
Radio altitude	D-value computer	Photo panel, flight log	SCR 718 radio altimeter
Pressure altitude	D-value computer and pressure altimeters	Digital, photo panel, flight log	None
D-value	D-value computer	Digital, photo panel, flight log	Hand computation
Temperature	Vortex thermometer	Digital, photo panel, flight log	None
Temperature	Stagnation thermometer	Photo panel	None

Table 1. - NHRP aircraft instrumentation system. (Cont.)

Information	Instrument	Recorders	Substitute
Temperature	Reverse-flow thermometer	12-channel oscillograph	None
Humidity	Infrared hygrometer	12-channel oscillograph, photo panel	None
*Sea surface temperature	Radiometer	Pen recorder, photo panel	None
Accelerations-vertical	*WADC system, NACA VGH recorder	6-channel oscillograph, VGH recorder	None
*Accelerations-lateral	WADC system	6-channel oscillograph	None
*Angle of attack	WADC system	6-channel oscillograph	None
Icing rate	NACA icing rate recorder	Icing rate recorder, photo panel	None
*Electric field	E.F. meter	12-channel oscillograph	None
*Liquid water content	Paper tape L.W.C. meter	12-channel oscillograph	None
*Liquid water content	Hot wire L.W.C. meter	12-channel oscillograph	None
*Cloud droplet size	Cloud droplet sampler	Microphotography, (Event indicated on 12-channel oscillograph)	None
Event signals	Switches in Meteorologist's position	Digital, photo panel	None
Radar echoes	AN/APS-23 (APS-64 on B-47)	0-15 camera (Time of each picture indicated on photo panel)	None
Time-lapse cloud pictures	Camera	Camera	None

* Not included in B-47 instrumentation.

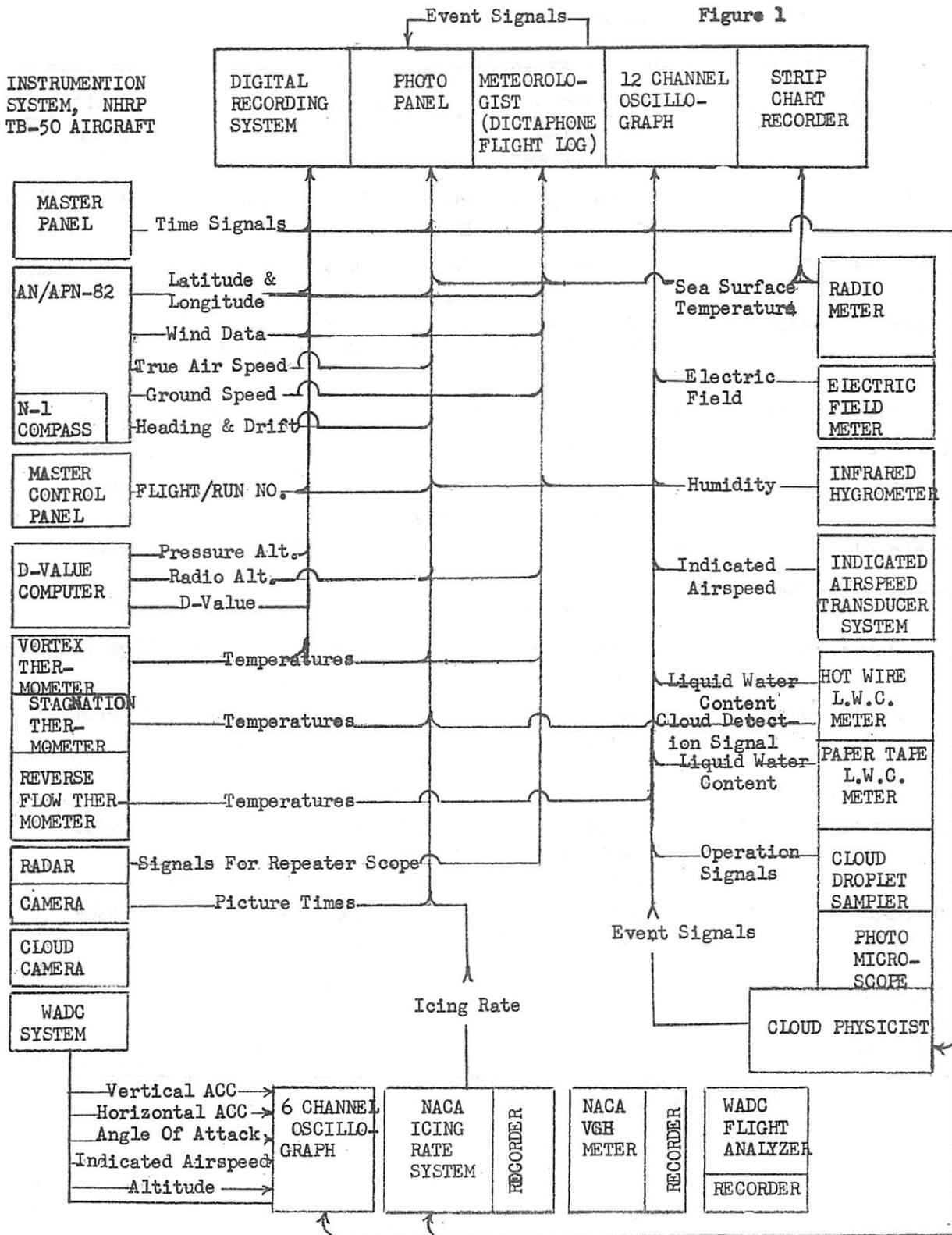


Figure 1. - Instrumentation system, NHRP TB-50 aircraft.

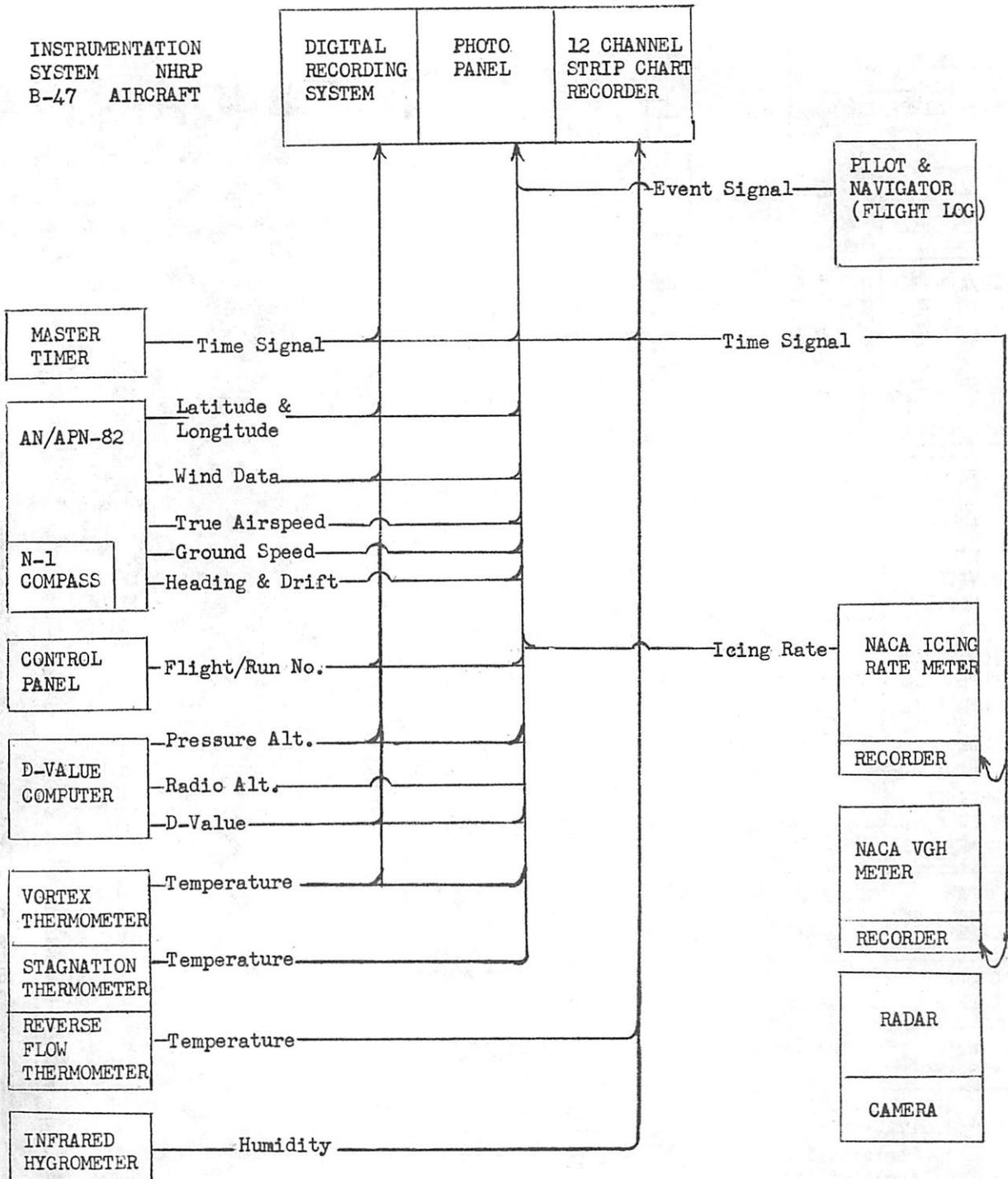


Figure 2. - Instrumentation system, NHRP B-47 aircraft.

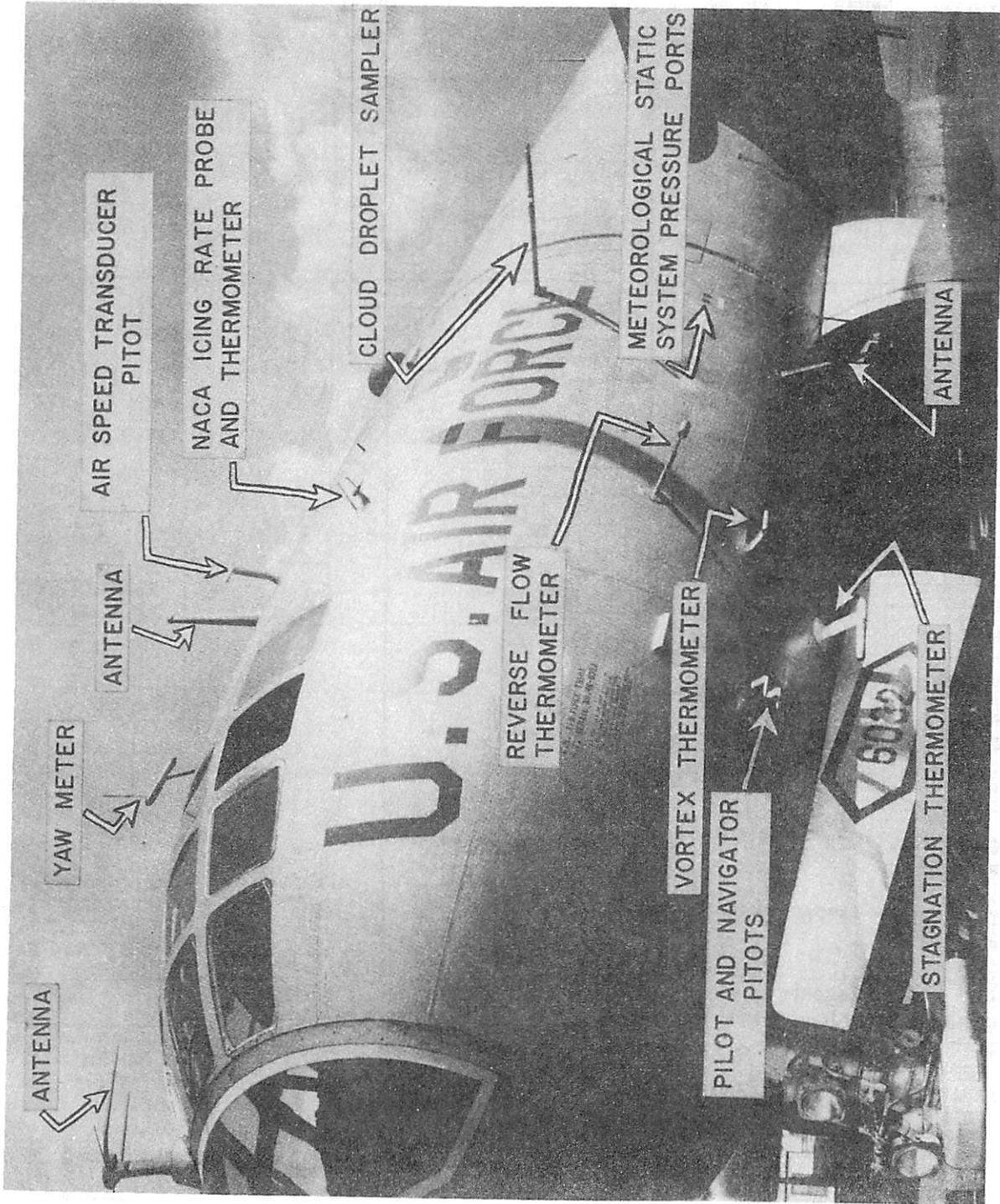


Figure 3. - Side view of B-50 showing sensing probes.

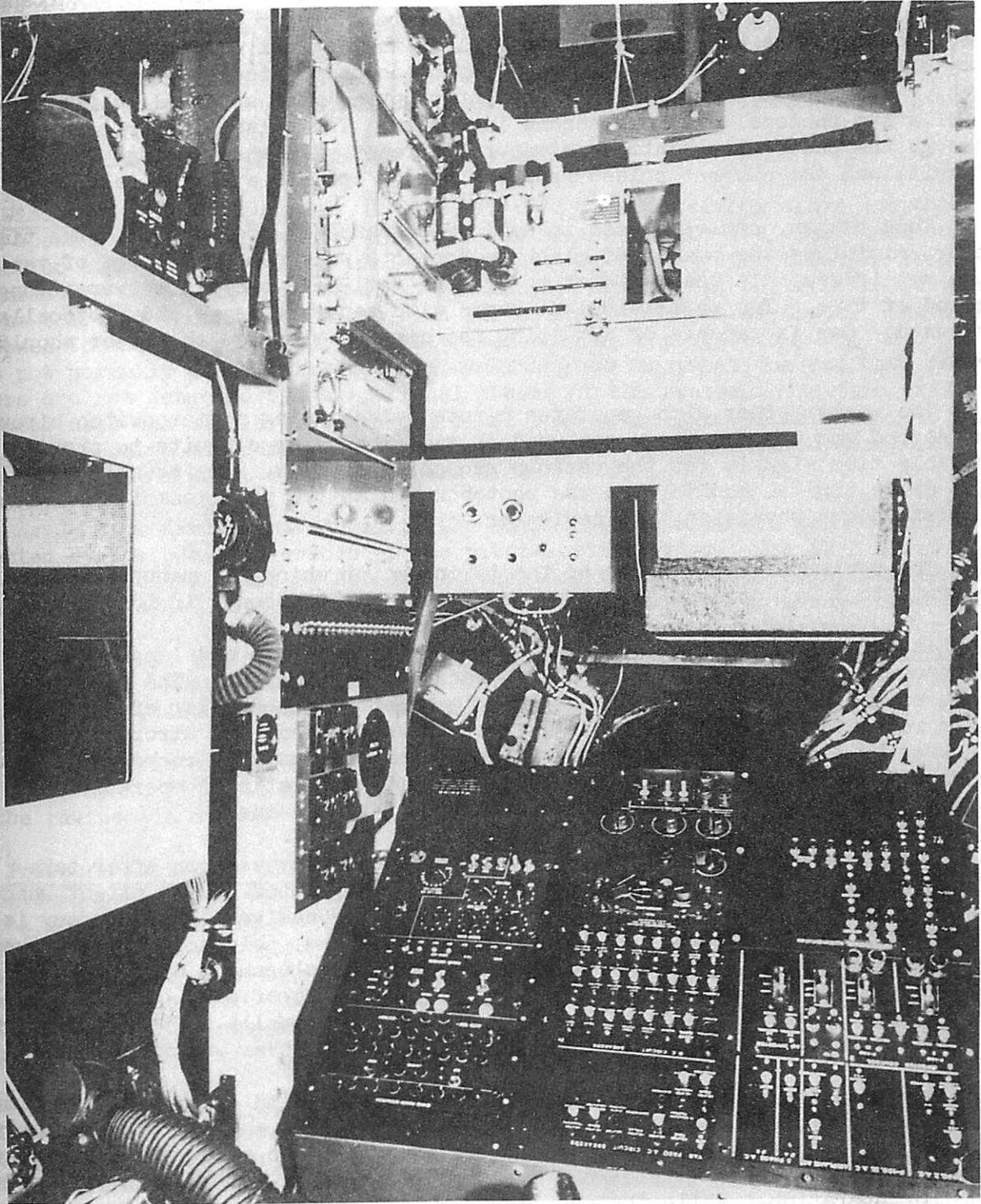


Figure 4. - B-50 Instrument layout in rear observer section.

A. MEASURING INSTRUMENTS

1. Time: The Master Timer. - The time signals which are recorded simultaneously with the meteorological data originate in a master timer which also serves to control the card punching interval of the digital recorder. The primary element of the timer is a 28V DC Haydon chronometrically-governed timing motor. This motor turns a light-beam-interrupting disk arranged to illuminate briefly two photocells at one-second intervals. The pulsed electric current through the photocells controls a saturable reactor in an AC bridge rectifier circuit, and the current pulses from the bridge operate a timing relay.

This rather complex system is employed because it does not load the timing motor, minimizes the number of electric contacts, and avoids the use of vacuum tube amplifiers. It was designed to promote fail-safe operation over a long period of time. Two parallel light beams with separate lamps and photocells are used. One is capable of actuating the circuit alone if the other should fail.

The master timer also generates minute pulses using a microswitch circuit. The second and minute pulses are used in stepping relay circuits to provide suitable time signals for the various recording systems. The second pulses also drive digital counters in the photobox and at the positions of the meteorologist, cloud physicist, and navigator.

The system is as accurate as the timing motor which the manufacturer rates accurate to ± 0.1 percent or, in terms of time, ± 36 seconds in 10 hours.

2. Latitude and Longitude: AN/APN-82 Radar. - Latitude and longitude are continuously computed by the AN/APN-82 radar navigation set. The equipment measures ground speed and drift angle by evaluating the Doppler effect on microwaves reflected from the ground. It uses these data and the aircraft heading measured by the N-1 compass system to make a continuous dead reckoning computation of latitude and longitude. The system is automatic in operation and completely independent of visibility and ground-based aids.

The computer is usually set to the proper coordinates soon after take-off, using a known navigational fix. It can be corrected during flight whenever it does not agree with known coordinates. The navigational accuracy is dependent upon the accuracy of the N-1 compass system, the accuracy of ground speed and drift calibrations of the system, and the alignment of the antenna with respect to the aircraft. Another possible source of error occurs because the magnetic variation must be set into the system manually. Its computations are also affected by surface currents when it is used over water.

During normal operation, the equipment computes wind speed and direction using true airspeed from an A-2 true airspeed computer, and its other measurements. During periods when conditions are such that the radar signal returned from the ground is not usable, the system automatically switches to the "memory mode" of operation. While the equipment is in the "memory mode" the ground speed and drift angle information is computed from the latest remembered wind values and the measured true airspeed and heading information. While the system is in memory, the computed latitudes and longitudes will be miscalculated

if the wind changes or if the true airspeed information is inaccurate.

Since the latitude and longitude are continuous dead reckoning computations, errors incurred during memory operation will be perpetuated after it returns to normal operation. Some of the conditions which cause automatic switch-over to memory operation are:

- a. Abnormal roll or pitch of the aircraft.
- b. Flight over abrupt cliffs or declivities when the aircraft is at low altitude
- c. Flight over a glass-smooth water surface.

3. Winds: AN/APN-82 Equipment. - The APN-82 system described above computes wind speed and direction unless it is in the memory mode. The wind speed and direction computer solves the wind-airspeed-groundspeed-vector triangle from the measured true airspeed, heading, groundspeed, and drift angle. The accuracy of the computed wind is dependent upon the accuracy of each of these. The true airspeed is the one parameter normally used only in the wind computation. It does not normally enter into the latitude-longitude computations and thus its errors are not detected by navigational checks of the system. The true airspeed computer uses the static pressure and flush bulb temperature information to make the density ratio and compressibility corrections to the indicated airspeeds measured from the pitot-static pressure differences.

Aside from errors introduced in the computer, the airspeed measurement is affected by the position errors of the pitot-static system. The NHRP aircraft are equipped with a means of setting corrections into the true airspeeds measured by their APN-82 systems. Since these aircraft are nearly always operated at normal cruising speed, the true airspeed corrections were determined for cruising speed at the operational altitudes and set into the system on subsequent flights. Post-hurricane-season flight calibrations refined these correction values, as discussed in the calibrations section below.

On the basis of Project experience with this equipment, it is felt that the winds measured by it are in general at least as accurate as those measured by the rawinsonde method.

4. Pressure Altitude: Cook D-Value System. - Pressure altitude is measured by a Kollsman pressure altitude synchrotel transmitter driving a pulse-type incremental servo system in the Cook Research Laboratories' D-Value computer. The output of this servo system changes in discrete increments corresponding to 10-foot changes in altitude. Laboratory calibrations against a mercury manometer showed that while these systems were accurate to only 4 percent and quite nonlinear, nevertheless they had hysteresis and repeatability errors of less than \pm 20 feet.

Pressure altitude is also indicated by, and recorded photographically from, Kollsman sensitive altimeters. These instruments are rated accurate to 1.5 percent by the manufacturer, but NHRP laboratory calibrations showed 2 percent to be a more realistic value. The calibrations also showed that corresponding readings differed very greatly during decreasing and increasing pressure sequences. The differences often amounted to 2 percent of the indicated altitudes even when the instruments were being continuously vibrated. These hysteresis and friction effects should be given serious consideration when this type of

instrument is used for meteorological purposes.

5. Radio Altitude: BC-788 and Cook D-Value Computer. - A slightly modified BC-788, the transmitter-receiver unit of the SCR-718 radio altitude equipment, is used to transmit, receive, and amplify the radio wave signal pulses fed to the Cook Research Laboratories' D-Value computer. The information consists of two pulses. The first is generated when the BC-788 transmits the radio wave pulse. The second pulse is generated by the received ground echo. The time elapsed between the two pulses is proportional to the altitude of the aircraft.

The D-Value computer uses the first pulse to generate a traveling magnetostriction wave at one end of a straight nickel ribbon. This wave travels relatively slowly along the ribbon at a constant rate and is sensed when it reaches a detection unit. The elapsed time between the generation and the detection of the wave is proportional to the distance between the pulse generation end of the ribbon and the detection unit. The elapsed time can be changed by means of a servo system which moves the detection unit back and forth along the ribbon.

The computer determines whether the radio echo pulse returns from the ground before or after the magnetostriction wave reaches the detector, and moves the detector along the ribbon until the two events occur simultaneously. When this has been achieved, the position of the detection unit is an analogue of the radio altitude. The mechanical position of the detector is easily converted to an angular position of a shaft geared to a synchro repeater.

One of the disadvantages of this system is that if a ground echo is not received, the nickel ribbon signal appears to be sensed ahead of the nonexistent echo signal, and the servo system increases the indicated radio altitude one increment. If enough ground echoes are lost the system tends to indicate greater than true radio altitude or to run up-scale until it reaches the end of the nickel ribbon.

The primary advantages of the system compared to the standard SCR-718 equipment operated by flight personnel are its objectivity of measurement, the elimination of inherent errors in the indicator scope, and its convenience for recording.

Absolute altitude can also be measured on the NHRP aircraft with a standard SCR-718 set. The indicator unit, I-152, presents the reference and echo pulses on a type J scope. The angular distance between the pips is calibrated in terms of altitude. The sweep speed has two settings corresponding to ranges of 5,000 and 50,000 feet of altitude. The SCR-718 equipment is considered accurate to ± 50 feet.

6. D-Value: Cook D-Value Computer. - The computer subtracts the indicated pressure altitude from the radio altitude by means of a simple mechanical differential. The indicated D-Value changes only in discrete steps of 10 feet because of the incremental feature of the radio and pressure altitude servo systems. Errors of the D-Values are the algebraic differences of the radio and pressure altitude errors. Since the pressure altitude system is highly nonlinear, D-Value corrections are irregular from altitude to altitude.

7. Temperature: - Three different types of thermometers are installed on the

NHRP aircraft to insure the measurement of temperature, to capitalize on the advantages of each type, and to allow comparison between the measurements when some doubt arises as to the accuracy of one instrument.

a. Vortex thermometer, ML-471/AMQ-8. - The vortex probe is mounted outside the plane in a position at which the flow of air is not greatly disturbed by the motion of the aircraft. It consists of a cylindrical radiation shield containing a fixed spiral vane and a resistance wire thermometer. In flight the air flows axially into the housing and is forced by the vane to form a vortex around the sensing element. It is stated by the manufacturer (Friez Instrument Division, Bendix Aviation Corporation) that the cooling effect at the center of the vortex compensates for dynamic heating in the airspeed range of 0.2 to 0.65 Mach, corresponding roughly to a true airspeed range of 130 to 400 knots at the operational altitudes of the NHRP aircraft. The manufacturer claims speed compensation within $\pm 0.5^{\circ}\text{C}$. within this range. The response time of the probe is approximately 10 seconds.

The resistance wire thermometer is used as one arm of an AC-excited, self-balancing, compensated Wheatstone bridge. When the bridge is unbalanced the resulting AC error signal is amplified and drives a servo motor which repositions a 10-turn potentiometer, thus rebalancing the bridge. In the NHRP aircraft a digital code wheel and the synchro outputs are geared to the potentiometer. The servo system requires about 22 seconds to slew through a 50° temperature change.

A "calibrate" switch on the front of the instrument is used to replace the sensing element with a fixed resistor. When this switch is held down the instrument should come to the temperature indicated on the case near the calibration switch. This check is usually performed at least three times during the NHRP flights. It checks the electrical system of the instrument, but not the temperature probe.

The manufacturer states that rain, fog, and snow introduce no detectable error and that the effect of icing conditions is negligible until $3/16$ inch of ice has built up on the probe. No provision is made for de-icing the probe.

b. Stagnation thermometer, AN/AMQ-7. - The Kollsman AMQ-7 temperature and humidity set measures the temperature within the probe, not the free air temperature. Because the probe is not designed to compensate for dynamic heating of the air, free air temperatures must be computed from the thermometer readings and true airspeed measurements.

The probe is mounted axially in the airstream. It consists of a double-walled cylindrical aluminum radiation shield containing a de-icing heater, an airflow baffle, and a screen surrounding the sensing elements. During flight the air flows through a large opening in the front of the probe, over the baffle, through the screen, past the temperature element, and out through 12 small holes near the rear of the probe. The speed of the air relative to the aircraft is greatly reduced before it reaches the sensing element and the pressure of the air is increased. The temperature increase caused by the adiabatic compression and frictional heating in the probe is proportional to the square of the true air speed.

The AMQ-7 electrical measuring system is quite similar to that of the AMQ-8 except that the use of a thermistor rather than a resistance wire element causes the output shaft position to be a nonlinear function of temperature.

Judging from the testing procedures outlined in the instruction book, the instrument can be considered accurate to $\pm 0.5^{\circ}\text{C}$. The servo system requires about 10 seconds to slew through a full scale change of thermistor resistance.

The AMQ-7 can not be used when appreciable amounts of liquid water are encountered or under icing conditions, but it can be de-iced and used later.

c. Reverse-flow thermometers, (1) The Cook All Weather Thermometer probe is equipped with a thermistor temperature element on the B-47 aircraft and with thermocouple elements on the two TB-50 aircraft. This probe employs the pressure distribution which results when air flows past a symmetrical airfoil to generate a relatively weak reverse flow of air inside the airfoil.

The probe and its supporting strut are shaped like a small airfoil and are mounted like a wing on the planes' fuselage. The supporting strut comprises about three-fourths of span of the airfoil.

The outer temperature-measuring portion of the airfoil is thermally insulated from the strut portion and chrome plated to reduce radiational heating. Two lines of slots, cut in both the top and bottom surfaces of the sensing probe in its thickest section, extend along the span of the airfoil. A third line of slots is cut in the trailing edge of the airfoil.

When air flows past the probe the air pressure is greater at the trailing edge of the airfoil than at its thickest section, and an air current is created inside the airfoil from the trailing edge slots to the slots at the thickest section. This reverse flow of air inside the airfoil is converged and directed by suitable ducting so that it properly ventilates the temperature-sensitive element contained inside.

This probe reduces the speed of the air somewhat less than the stagnation thermometer does, but its readings still must be corrected for airspeed. Tests made by the manufacturer show that the recovery factor is constant. The probe is equipped with an automatic de-icing system which employs the same principles as the icing rate meter described below.

The chief advantage of this probe is its ability to measure air temperatures when the aircraft is flying in clouds and precipitation. The cloud droplets and hydrometeors do not enter the trailing edge of the airfoil because of their momentum. The TB-50 reverse-flow probes were equipped with thermocouples in order to obtain the short response times important in cloud physics research.

In the TB-50 aircraft the thermocouple current is amplified by a thermocouple amplifier designed at the Department of Meteorology, University of Chicago. This unit contains the compensating reference junction network for the thermocouple. In the B-47 aircraft the thermistor is used as one arm of an off-balance DC Wheatstone bridge circuit.

The absolute accuracy of the thermocouple thermometers cannot be consi-

dered much better than $\pm 1^\circ\text{C}$. because of the long thermocouple lead wires between the probes and the amplifiers, and because of possible inaccuracies in the reference junction units. These instruments, however, can be considered sensitive to air temperature changes of 0.1°C .

(2) University of Chicago Reverse-Flow Thermometer. - During the 1956 flight program, TB-50 aircraft no. 46032 was temporarily equipped with a reverse-flow thermometer furnished by the University of Chicago Cloud Physics Project. It operates on the same principle as the Cook Research Laboratories' probe, but is quite different in appearance. It consists of a cylindrical housing and radiation shield mounted axially in the airstream. The forward end of the cylinder is closed by a bulkhead which contains several large holes. Immediately ahead of the bulkhead, but separated from it slightly, is a thick disk perpendicular to the airstream and of the same diameter as the cylinder. The other end of the cylinder is open. During flight, the air flows into the after end of the cylinder and out through the gap between the cylinder and disk. The thermocouple is mounted in the center of the cylinder near its forward end. This probe was used with the same circuitry provided for the Cook probe. It has approximately the same features as the Cook All Weather Thermometer probe, except that there is no means of de-icing it.

8. Humidity: Infrared Hygrometer. - The infrared hygrometers used on the NHRP aircraft were developed and constructed by the Instrumental Engineering Division of the U. S. Weather Bureau. The hygrometers measure the absolute humidity of an air sample by sensing the difference between transmissions of infrared radiations in two different spectral bands. The two bands are a 1.37-micron water vapor absorption band and a 1.24-micron reference band. The instrument does not measure the transmissions, but employs a servo system to change the color temperature of the light source until the energies transmitted in the two bands are equal. Thus, the color temperature of the lamp becomes a function of the measured humidity.

The collimated beam of light from a tungsten source is intercepted by a filter wheel composed of eight 45° sectors, each of which is an interference-type filter. Four of the filters pass the water vapor absorption band, and the other four the reference band. The filters are located alternately in the wheel which is rotated through the light beam by a synchronous motor, so that the infrared beam entering the sensing chamber is composed alternately of wavelengths in the two spectral bands.

Each type of filter is interposed in the beam at a frequency of 60 cycles per second. When the absolute humidity of the sampled air increases, the 1.37-micron radiation transmitted through the sample is decreased relative to the 1.24-micron radiation transmitted, and the intensity of the radiation in the beam reaching a photocell fluctuates at a 60-cycle rate. The electrical output from the lead sulfide photocell then contains a 60-cycle signal component, which is separated from the steady portion of the photocell output and used to drive an amplifier tuned for 60-cycle signals. The phase-sensitive amplifier is used to drive a servo motor which changes the voltage applied to the light source until there is enough extra energy transmitted in the water vapor absorption band to equalize the energies in the two bands reaching the photocell. The color temperature of the lamp is then a measure of the humidity of the sample.

The light source used is a specially designed tungsten-filament incandescent bulb with a heavy gage spiral filament. The infrared spectral distribution of the radiation from this lamp has proved to be a very stable function of the lamp voltage.

The color temperature is measured with a selenium-barrier-type monitor photocell and the DC current generated by the cell is the output signal of the instrument. The monitor photocell is used because its current is a more realistic, a more sensitive, and a more proportional measure of humidity than the lamp voltage would be.

As a concession to space limitations, the airborne models used by NHRP employ a folded light path made possible by three front surface aluminized mirrors. The instrument also contains a dry reference path obtained by designing into it an interior chamber dried with phosphorous pentoxide. Two mirrors are swung into the light path and divert the beam through this chamber of constant humidity. In this way a reference reading can be obtained which reflects only changes which might occur in the instrument itself. A timing motor is employed which causes a reference reading to be taken each half hour. The reference reading can also be made whenever the operator desires.

The sensing path is enclosed in an aluminum chamber and air is brought to this chamber through a 2-inch-diameter hose from a scoop unit on the skin of the aircraft. The air is drawn out through a similar hose leading to a suction port of the same unit. The scoop unit is designed to prevent liquid water drops from entering the intake when the plane is in flight.

The designers of the hygrometer state that it is sensitive to 25 milligrams of water vapor per cubic meter at an absolute humidity less than 1 gram per cubic meter, and has a dewpoint accuracy of 1.1°C . for dewpoints between 15° and -7°C ., and 0.3°C . between -7° and -18°C .

Response time of the instrument for an instantaneous change of water vapor content in the sensing path is less than 5 seconds. It is estimated that the time required to completely change the air in the sensing chamber is of the order of 15 seconds.

Provision has been made to measure the air pressure in the sensing chamber. It is expected, however, that the intake and outlet pressure drops will be regulated until the air density in the chamber approximates that of the free air.

9. Sea Surface Temperature: The Radiometer. - The radiometer used in the aircraft was designed and constructed by Dr. W. Richardson of Woods Hole Oceanographic Institution. It determines sea surface temperature by measuring the infrared radiation from the sea surface. The infrared radiation for reasonable sea surface temperatures is centered in the 10-micron wavelength region and is transmitted through the atmosphere in a window between the 6-7-micron water vapor absorption band and the 13-micron carbon dioxide band.

The instrument's optical system consists of a silver chloride lens which focuses the infrared radiation on the detector and a first surface plexiglass chopper mirror with two 90° sectors open. The mirror is rotated by a small synchronous motor and is located so that the detector receives infrared energy

alternately from the sea surface and from a reference black body maintained at a constant temperature. The bolometer detector consists of two flakes of thermistor material. One of the flakes is exposed to the radiation from the lens and the other is shielded from radiation and provides compensation for temperature changes within the detector. The thermistors are used in a bridge circuit biased with batteries. The output of the bridge is an alternating voltage whose amplitude is a function of the sea surface temperature. The signal is amplified and then attenuated by an adjustable gain control. It is then rectified and used to drive a Leeds and Northrup Speedomax pen recorder.

The reference black body is a thin-walled brass cone wound with a heating coil. It has a thermistor in its apex. The inner surface of the cone, viewed by the detector, is blackened to increase its radiational efficiency. The thermistor is used with a proportional type temperature controller to regulate the current through the heating coil.

The instrument is calibrated by direct comparison of water temperatures in a shallow pan held below the radiometer. When the water temperature is the same as the equivalent radiation temperature of the black body, the output signal is zero. The temperature controller is adjusted so that the black body temperature corresponds to the maximum sea surface temperature to be measured. The signal and the recorder readings increase with decreasing sea surface temperatures.

The instrument cannot be considered reliable when the aircraft is above 1,500 feet because of the radiation from atmospheric carbon dioxide and water vapor. This model of the instrument is considered accurate to 1° or 2°C. when used at low levels, but has sensitivity of 0.1°C.

10. Electric Field: Electric Field Meter. - The electric field meter used on NHRP aircraft was developed by Dr. Ross Gunn, Director of Physical Research of the U. S. Weather Bureau. This instrument measures the electric field near the aircraft skin.

The electric field sensor is a figure eight formed of aluminum wire. When in use, it is rotated about its center in the plane of the figure eight. It is installed in the belly of the aircraft over a slot in the aircraft's skin. The axis of rotation of the sensor is inside the aircraft and only about 1/2 of each loop of the rotor ever projects into the airstream.

The rotor is turned by a dynamometer used to generate the plate voltages for the electron tubes in the instrument. The dynamometer also turns a magnet which generates electric currents in two coils. These currents are used to serve as a phase reference to the signal as described below.

An alternating electric charge is electrostatically induced in the rotor as it is rotated in and out of the electric field outside the aircraft. The induced charges are allowed to drain off through a resistor and the alternating voltage developed across the resistor is applied to a current amplifier circuit. The signal is then attenuated in a range selector circuit and amplified by a commercial phono-amplifier. The signal at this stage is an alternating voltage, the amplitude of which is proportional to the electric field. The phase of the signal depends upon whether negative or positive charges are in-

duced in the rotor by the electric field. The phase of the signal must be compared with the phase of alternating currents generated by the rotating magnet in order to determine whether the external electric field is positive or negative. This is accomplished by a phase sensitive demodulator circuit whose output is a direct current. The current is positive if a positive charge is induced in the rotor by the external electric field. It should be noted that a positive external electric field will induce a negative charge on the sensor resulting in a negative output current.

This instrument measures the electric field near the skin of the aircraft. This field exists between the electric charges on the skin of the aircraft and charged particles in the atmosphere. When an aircraft is in flight it takes on an electric charge because charged particles are ejected in the engine exhausts, and because the frictional motion of haze particles and ice crystals along its skin causes an exchange of charges. The static charge on the aircraft affects the electric field measured by the instrument. The factor of the measured electric field caused by charges on the aircraft in general is fairly constant or slowly changing unless dry snow is encountered. The field caused by electric activity in cumulus formations is more transient because of the motion of the aircraft. Prior to lightning strikes on the aircraft, the field is increased very markedly and is then discharged by the strike.

One other consideration is that the sensing unit is on the belly of the NHRP aircraft and tends to be shielded from charged particles above the flight level. The instrument is considered accurate to ± 4 percent when calibrated on the aircraft.

11. Radar Echoes: AN/APS-23 Radar. - The AN/APS-23 radar is used in the NHRP aircraft primarily for cloud surveillance and flight control. This unit is an X-band (3 cm.) radar designed primarily for navigation and mapping purposes. It can be set for various ranges from 5 to 200 miles, and has a power output of 55 kw. for ranges less than 80 miles, and 44 kw. for greater ranges. The output pulse length is $3/8$ microsecond on the ranges between 5 and 50 miles, 1 microsecond for those from 50 to 80 miles, and 5 microseconds for the greater ranges. The receiver sensitivity is 8 dbm. The half power limits of the antenna radiation lobe subtend angles of 1.5° in the horizontal and 55° in the vertical.

The power distribution in the vertical plane is shaped by the antenna into a cosecant squared pattern. This pattern provides return signals from targets at various ranges of relatively equal strength. The antenna rotates around a vertical axis and can be depressed to 14° below the horizontal. PPI scopes are used for echo presentation and an O-15 Fairchild camera is employed on the navigator's scope. It photographs the scope presentation, a clock, and a digital picture counter. The NHRP TB-50 aircraft have PPI repeater scopes installed at the meteorologists' stations.

The AN/APS-64 radar is used in the NHRP B-47 aircraft. This set is very similar to the APS-23 except that a larger PPI scope is employed.

12. Icing: NACA Icing Rate System. - The NACA statistical icing rate meters were developed and constructed at the Lewis Flight Propulsion Laboratory to provide a simple instrument capable of routine use on commercial airliners,

Air Force operational aircraft, and special research aircraft. An accumulation of data from these instruments is expected to provide pertinent meteorological information necessary in the design of ice protection systems for aircraft. The NACA officials are allowing NHRP to process the icing rate records obtained on the research flights so that NHRP will have immediate access to the data. The system records icing rate, pressure altitude, air speed, and temperature.

The icing rate system consists of an ice collecting element and thermometer unit, a recorder and control unit, a cumulative timer and coding unit, and a remote indicator unit.

The ice collecting element is a U-shaped tube mounted perpendicular to the flight path. The bottom of the U-shaped tube is actually a small phosphor-bronze tube in which ten small total pressure holes have been drilled. The unit is mounted with the holes facing forward so that the air pressure within the tube will be approximately pitot pressure. The U-tube is sealed except for the holes, and is pneumatically connected to the recorder control unit. In the recorder control unit the ice-collecting element pressure line is vented to an external special static port through a small orifice and is also connected to one side of a differential pressure switch. The opposing side of the pressure switch is connected to the pitot pressure line.

When the holes in the ice-collecting element are open, the pressure switch is not activated because it has pitot pressure on both sides of its diaphragm, but when the holes in the ice-collecting unit are sealed by ice, the pressure in the line decreases to static pressure and the switch is closed. Continuous cyclic operation is obtained by allowing the differential pressure switch to energize an electric heating circuit which de-ices the ice-collecting U-tube. The heat-off time of this cyclic process is used as a measure of icing rate.

The recorder control unit also contains the recording film mechanism, air speed and altitude pressure capsules, and the electric components controlling the operating cycle of the system. The record is made on photographic film contained in a drum which can be removed from the recorder. The film drive motor is governor-controlled to provide a constant film speed of about 1 inch per minute. The film in the drums is adequate for about four hours of recording in continuous icing conditions. The airspeed and altitude capsules are actuated from the pitot and static pressure lines and their deflections are magnified by a light beam and mirror system which records the deflections on the photographic film. An electric solenoid, in parallel with the heater circuit, controls a mirror which serves to record the icing and de-icing periods on the film.

The temperature is measured by a resistance-wire-type thermometer mounted in a shielded, reverse-flow-type probe located near the ice-collecting element. The resistance temperature element forms one leg of an off-balance Wheatstone bridge circuit which actuates a light beam galvanometer in the recorder.

The cumulative timer and coding unit serves to interrupt the temperature track record every two minutes and employs the temperature recording galvanometer to produce three steps in the temperature trace which can be decoded in terms of the number of minutes which have elapsed since the system was turned on. About 20 seconds of the temperature record is lost at each time coding.

In the NHRP aircraft, the coding unit is controlled by the master timer unit of the digital equipment.

The system can be operated either continuously or automatically. When set in the automatic mode, the recorder does not start until the de-icing circuit is energized. The recorder then operates during icing conditions and continues to operate until 10 minutes after they cease.

The remote indicator unit consists of three indicating lamps and a counter which indicates the icing encounter number. It advances one count each time the recorder starts. Thus, it counts each time the aircraft encounters icing conditions separated by a period greater than 10 minutes. The three indicating lights show: (1) whether the recorder is operating, (2) when the de-icing circuit is energized, and (3) whether the film drum is exhausted.

13. Vertical Acceleration: NACA VGH Recorders. - The NACA VGH recorder makes a 10-hour record of the aircraft's airspeed, altitude, and vertical accelerations. The instrument contains two pressure-sensitive elements that measure the static pressure and the difference between the static and pitot pressures. A galvanometer is used to measure the electrical signal from the strain gage type acceleration transmitter mounted near the center of gravity of the aircraft. The deflections of recording elements rotate mirrors which change the positions of reflected lamp images on the photo-sensitive record paper. The recording is made on a 200-foot roll of 70-mm. photographic paper moving at a rate of 20 feet per hour. The paper is used in a removable recording drum which contains the complete paper-advancing mechanism. The Gust Loads Branch of the National Advisory Committee for Aeronautics furnishes NHRP with the loaded film drums which are returned to them unopened after the flights. The NACA officials have agreed to process the records and furnish NHRP with the data.

14. Turbulence: Wright Air Development Command Instrumentation System. - The WADC turbulence research instrumentation is completely independent of the other NHRP aircraft data systems. Four strain gage type accelerometers are employed. There are both vertical and horizontal accelerometers installed near the center of gravity of each aircraft and vertical accelerometers located in the nodal points of each wing. The units in the wings are wired in series so that opposing accelerations tend to be eliminated from their record. These units are mounted at the nodal points of the wings because the TB-50's so equipped are flexible-wing aircraft.

Two strain gage type pressure transducers are used to measure the difference between the pitot and static pressure. The angle of attack is measured by a Statham "Arrowhead" transducer installed on the forward section of the fuselage.

The signals from these units are recorded on a Heiland 6-channel oscillograph.

The WADC representatives also installed Hatheway Flight Analysers in the aircraft during the flight season. These completely self-contained recorders make a continuous chart record of airspeed, altitude, and vertical accelerations.

The data reduction of the 6-channel oscillograph and the flight analyzer records will be accomplished by Project Globe at the University of Dayton, Dayton, Ohio.

15. Airspeed: Statham Pressure Transducer and I.A.S. Meters. - The Statham, Model P96, strain gage type pressure transducer is connected between the meteorological balanced static system and a special pitot tube. It is located very close to the pitot tube in order to minimize the response time of the system. The transducer is used with a Statham type CB 19 control unit which provides fast responding measurements of indicated airspeed which are useful in cloud physics and turbulence research. The range of the system is 0 to 2 lb. per square inch, or approximately 0 to 280 knots indicated airspeed. It is accurate to approximately 1 percent.

The indicated airspeed is also recorded on the photo panels which display Kollsman indicated airspeed meters. The laboratory calibration of these instruments shows that they are accurate to ± 2 knots, and repeatable to ± 1 knot.

The true airspeed recorded on the photo panel is derived from the AN/APN-82 system and is the same true airspeed used in the APN-82 wind computations.

16. Cloud Physics Instrumentation: - This section is a condensed presentation of certain portions of a report being prepared by the Department of Meteorology, University of Chicago, which covers nearly all of the instruments essential to the cloud physics research program. Only three of these instruments are described in this section of the report; the reverse-flow thermometers, the airspeed transducers, and the 12-channel Heiland oscillographs are discussed in other sections.

The cloud physics instrumentation was incomplete during the 1956 flight season. The first B-50 delivered to West Palm Beach contained neither the cloud droplet sampler nor the liquid water content meters. The second B-50 was delivered with the droplet sampler probe installed, but with other installations incomplete. The University of Chicago scientists managed to install the other cloud droplet sampler components and the hot-wire liquid water content meter in the second B-50 during the flight program.

a. Pneumatic cloud droplet sampler. - The cloud droplet sampling equipment consists of a probe unit, a sampling timer, and a microscope arranged for the photography of the droplet samples. This equipment was developed at the University of Chicago.

Probe unit: The probe unit was mounted in the forward pressurized compartment on the port side just forward of the bulkhead of the front bomb bay. It was designed to permit the momentary exposure of oil-coated glass slides in the airstream outside an aircraft. The cloud droplet sample is collected by the impaction method. After exposure, the slides are drawn back into the aircraft and photographed through a 150-power microscope.

The droplet sampler probe can be compared to a pneumatic gun. Each slide is mounted on a metal slide holder which is used as a bullet. Four of the slide holders are loaded into a revolving cylinder designed to function like the cylinder of a "revolver" type firearm. Each slide holder can be rotated

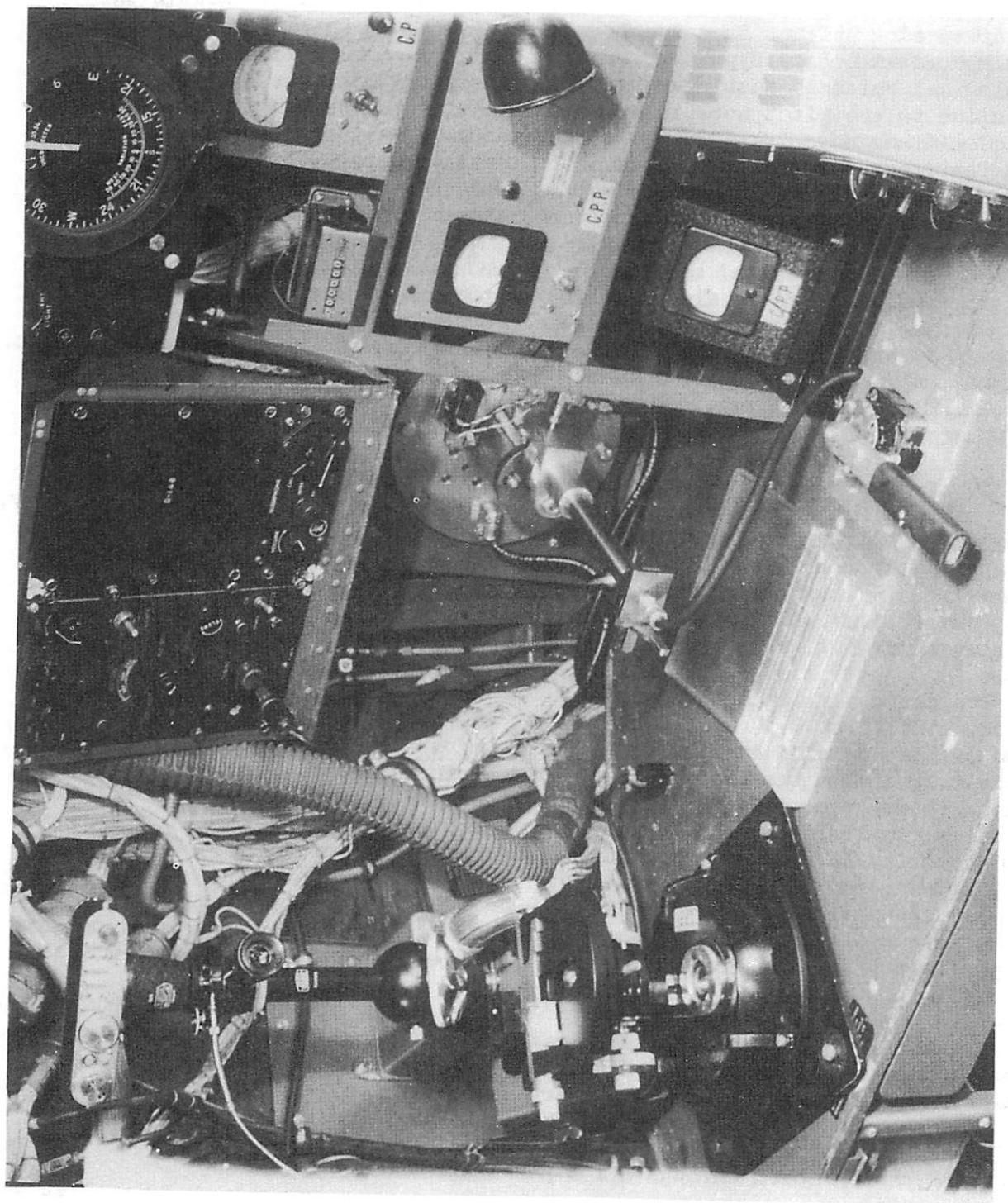


Figure 5. - Cloud physicist's station in TB-50 (Univ. of Chicago, Cloud Physics Project).

into the "firing position" in line with the "barrel" of the sampler probe. Compressed air is then applied to the rear of the slide holder through a control valve and the holder is blown through the barrel, past an open gap, and into a storage tube at the outboard end of the probe. The slide holders are notched to move along a key way in the barrel so that the slides will be exposed perpendicular to the airstream flowing through the gap in the probe. The four slides can be exposed in rapid sequence or singly as the operator desires.

When a holder reaches the storage tube its exposed slide enters a cavity in the rear of the holder which preceded it. The first slide enters a special cover slug which is sent through in preparation for the sampling sequence. The slide holders are returned to the pressurized compartment as a unit by valving compressed air to the outboard end of the storage tube. The slides remain covered during their recovery.

The pneumatic system is designed so that the holders are propelled by the pressure difference between the positive pressure side of the pump and the air pressure outside the aircraft. A pressure tank is used to help stabilize this pressure head. The slide exposure time depends upon the manipulation of the four-way control valve and can be varied between 10 and 40 milliseconds.

Cloud sampling timer: The exposure period of the slides must be known in order to draw conclusions concerning the quantitative droplet size spectrum. The exposure period is related to the speed of the slide as it passes the gap in the probe. This speed is determined by measuring the speed of the slide holders just before they cross the gap. There are two insulated electrical contacts in the barrel just inboard of the gap. As a slide holder passes, it makes a momentary electrical connection between these contacts and completes the charging circuit of a capacitor. The capacitor's charge is allowed to drain off through a high-resistance circuit including the Heiland 12-channel oscillograph galvanometers.

Microscope for droplet photograph: The cloud droplets in the oil film on the slides are photographed immediately after their recovery from the pneumatic sampler probe. The photographic equipment consists of a standard Leitz microscope fitted with a Leica camera back using 35-mm. film. The microscope is equipped with a special carriage to hold the slides and is specially mounted to reduce the effects of shock and vibration.

b. Liquid water content meters. - Two essentially different liquid water content meters were selected for use on the NHRP B-50 aircraft because no single instrument was considered completely satisfactory for the measurements desired. The use of both instruments was expected to increase the probability of obtaining useful data.

Paper tape liquid water meter: This meter is an adaptation of an instrument developed by the Division of Radiophysics, Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.) of Australia. It was constructed at the University of Chicago. The device continuously measures the electric conductance of a chemically treated paper tape moved past a narrow slit open to the impinging airstream. As cloud droplets or raindrops are impacted upon the

paper, the electrolytic conductance of the paper changes in direct proportion to the amount of water absorbed.

The instrument is designed to accommodate a 2400-foot roll of paper in order to permit continuous operation for a period of 8 hours, and is arranged so that the paper exposure slot can be closed to protect the paper during take-off or when the instrument is not in use.

Hot wire liquid water content meter: The hot wire liquid water content meters were manufactured by Johnson-Williams, Ltd., of Palo Alto, Calif. This instrument is a commercial version of a device developed by the NACA Laboratories.

The probe consists of a small cylindrical shield held on two tubular supports and mounted so that the airstream will flow through the cylinder. Inside the cylinder there are two pieces of resistance wire which are connected as adjacent arms in a balanced Wheatstone bridge circuit. Both wires are heated by the bridge current. One of the resistance wires is formed into a loop and is exposed perpendicular to the airflow. The other wire is stretched along the bottom of the cylinder and is shielded from the airstream. As water droplets strike the looped wire they are evaporated by the heat of the wire and the wire is cooled. The resulting change of the wire's resistance unbalances the bridge circuit. The bridge signal is used as a measure of the liquid water content of the air.

The calibration of this instrument has not been well established. It is hoped that certain tests now in progress at the University of Chicago will demonstrate the usefulness of the relatively simple device.

17. Meteorological Pitot-Static System: The static pressure field surrounding an airplane in flight is appreciably disturbed by yaw. An excess of static pressure is produced on one side of the aircraft and a pressure deficiency on the other side. To minimize the effect of yaw, two special static ports have been provided on the NHRP aircraft for the meteorological instruments. They are located directly opposite each other and are united in one line leading to the meteorological instruments. The lines connecting the two static ports to the common static line are of equal length and capacity in order to correctly balance pressure excess with pressure deficiency. The capacity of a pitot-static system, and therefore its lag, increases as the number of instruments it serves. To minimize this lag, NHRP meteorological instruments are connected to a special pitot system and the special balanced static system. The aircraft operational instruments are on the regular pitot-static systems. This separate arrangement also allows work on the meteorological system without disturbing the operational instrumentation. Instruments on the special pitot-static system are the D-value computer, VGH recorder, icing rate recorder, indicated airspeed pressure transducer, pressure altimeters, and I.A.S. meters in the photo panel, and true airspeed computer of the AN/APN-82.

B. RECORDING AND INDICATING SYSTEMS

1. Digital Recording and Indicating Systems: The digital recording system is used to record the routinely important meteorological data on standard 80-column IBM cards. Its chief component is a modified IBM 523 gang punch. The

main advantage of this rather complex recording method is that the data stored on the cards during flight can be readily printed out, plotted out, sorted, or even used in numerical computations as soon as the aircraft returns from a mission. Moreover, a digital recording system of this type introduces very little additional error into the measurements.

Nine channels of information are recorded on the cards. They are as follows:

Channel	Information	Data Source	Value of one bit
1	Time	Master timer	1 second
2	Latitude	AN/APN-82	1/4 min. of arc
3	Longitude	AN/APN-82	1/4 min. of arc
4	Flight and run numbers	Manually set	Units
5	Wind direction	AN/APN-82	0.703125 deg.
6	Wind speed	AN/APN-82	0.703125 kt.
7	Pressure altitude	D-value computer	10 feet
8	D-value	D-value computer	10 feet
9	Temperature	AMQ-8	0.10°C.

With the exception of the flight and run numbers and time, the information all occurs as shaft position analog data. It is converted to digital data by code wheels geared to shafts. This accounts for the odd increments used for wind direction. The cyclic nature of this parameter has made the division of 360° into 512 bits necessary because there are 512 bits to one revolution of the standard code wheel used. The same increment was used for wind speed in order to simplify the design of the system.

Servo repeater and digitizer unit: Where possible, the code wheels were attached directly to the measuring instruments, but in the cases of latitude, longitude, and wind speed and direction, it was necessary to employ servo amplifiers to drive the code wheels. These servo systems are grouped in the servo repeater and digitizer unit.

Time and distance intervalometer unit: Cards can be punched at various intervals of time or of distance traveled. A card is punched when the time and distance unit emits a "record" pulse. The time and distance unit accepts either time pulses from the master timer or distance-traveled pulses from the AM-755 distance-traveled amplifier unit of the AN/APN-82 equipment. It divides the pulses down into the interval set into the selector switches on the master control panel. Any one of the following recording intervals can be selected.

Time

1, 2, 3, 4, 5, 6, 7, 10, 12, 15,
20, 30, 40, 50, or 60 seconds

Distance

0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1.0,
2.0, 3.0, 4.0, or 5.0 nautical miles

DIGITAL RECORDING SYSTEM

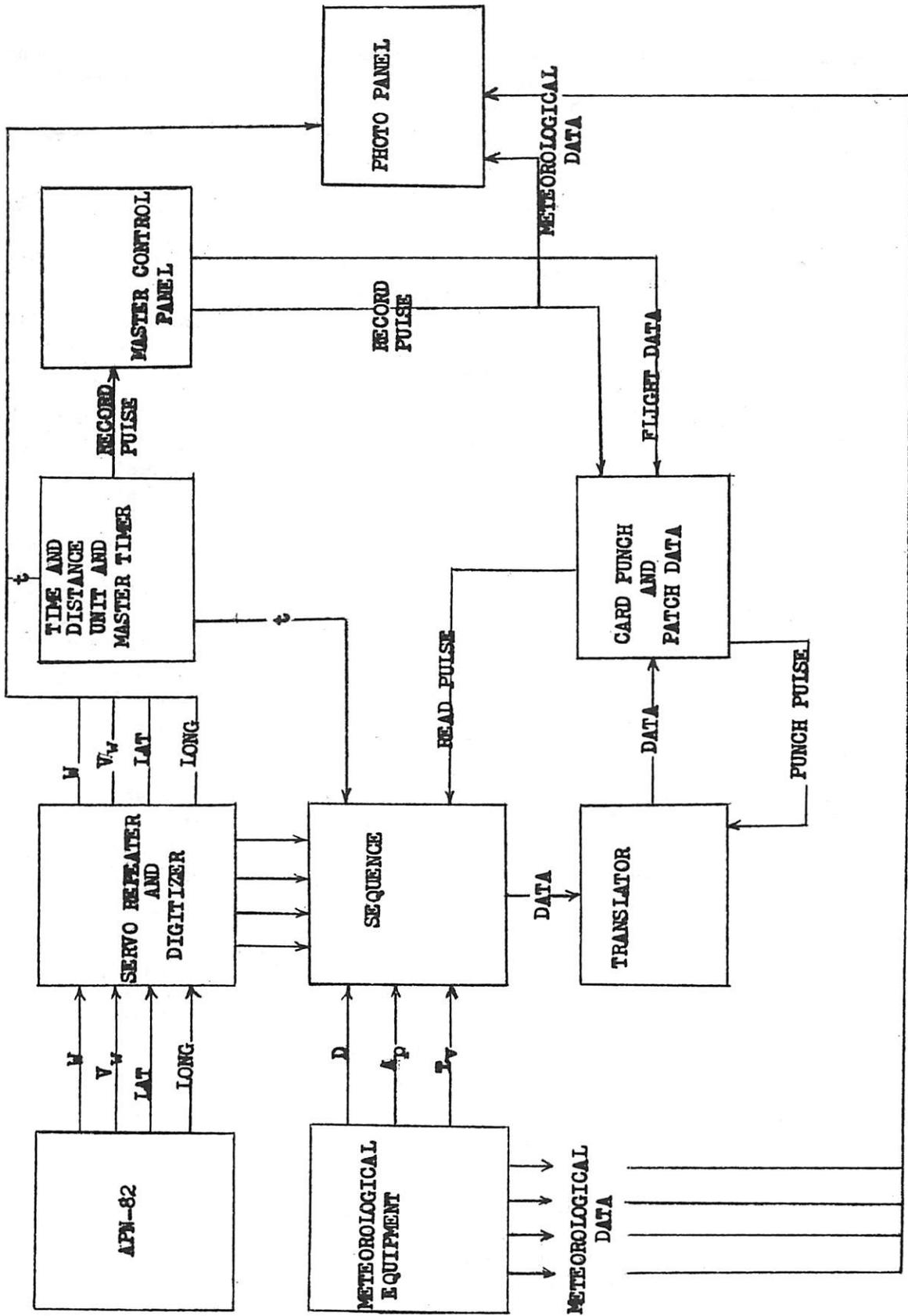


Figure 6. - Digital recording system

The "record" pulse starts the card punching cycle of the IBM punch and operates the recording camera in the photo panel box.

Gang punch sequence switches: The gang punch does not punch all of the holes in the card at once, but only one row at a time. It must move the card, stop it and punch one row, move it again, and so forth. The "record" pulse only starts the punching cycle. The sequence switches in the gang punch do the job of sequentially pulsing the code wheels. When the card has been moved they send the "read" pulses to the proper code wheels so that the right information will be punched into the new row. The code wheels can be thought of as complex switches. When one of them is pulsed it returns the pulse through some of the wires leading from it to the sequence control unit. Each wire corresponds to a binary digit.

Sequence control unit: The binary data pulses from the code wheels are collected in the sequence control box. In series with each "read" pulse wire is a diode which eliminates any possibility of pulses traveling through the system in the wrong direction and acting as spurious "read" pulses.

Translator unit: The data pulses from the code wheels do not have enough power to operate the card punch magnets. The code wheels are not able to conduct enough current without damage. Also the data from the code wheels is in double brush binary code and must be translated to pure binary before use in the card punch. Relay circuits in the translator convert the data to pure binary form and provide the high-current pulses from the card punch magnets.

The translator relays are the weakest link in the digital system. However, they can be checked whenever the punch is not in operation by employing stepping switch circuits in the sequence control unit. These checking circuits sequentially check all of the translator relays and light one of a bank of signal lamps on the master control panel if the corresponding relay is not operating properly.

Flight/run and time channels: The flight and run numbers are punched into every card. They are manually set with selector switches on the master control panel. They are punched in decimal form. The cards are numbered serially from 1 to 99 by an automatic counting circuit in the time and distance unit. These "data numbers" are punched in decimal form on each card.

Gang punch: The IBM gang punches used in the aircraft have been rather extensively modified by the General Precision Laboratory. They have been reduced to about one-quarter the size of the original units leased from IBM. Spring-loaded card depressors are used to hold the cards in the feed hoppers during flight turbulence, and a light-and-buzzer system has been installed to warn the flight technician instantly if a card jam should occur.

It takes approximately 0.6 seconds for each card to pass through the machine and the data recorded on one card is sampled within a period of 0.5 seconds.

2. Photo Panel Recording System: - The photographed instrument panel forms the rear wall of the photo box. The front wall or door of the box contains a large one-way mirror with the reflecting face inside. The recording camera is placed outside the photo box behind a hole in the center of the photo panel. It photo-

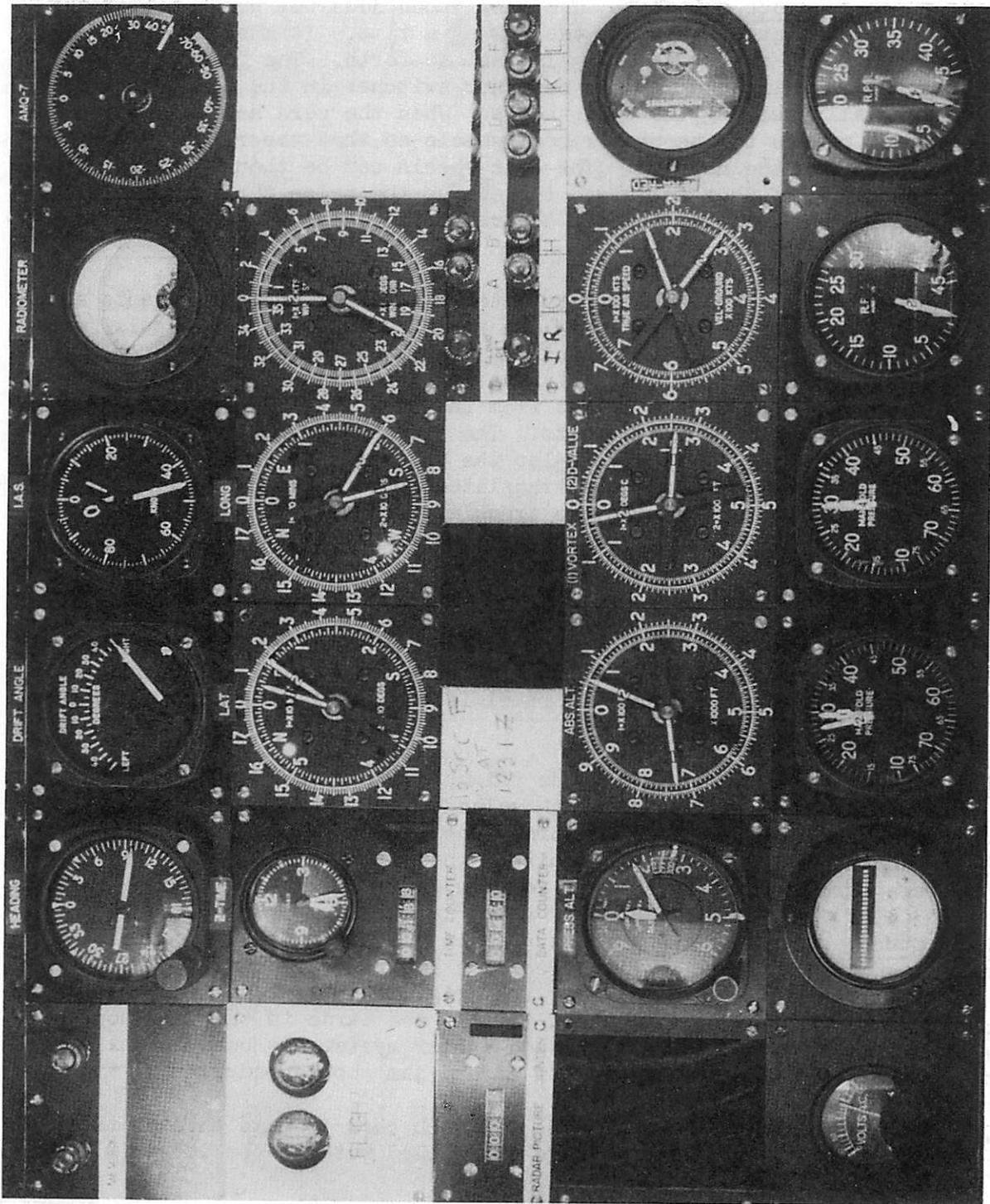


Figure 7. - Photo panel

AIR
 SIGNAL
 BROADCAST
 - 030000 01

graphs the image of the photo panel on the mirror. The photo panel is illuminated by two vertical rows of lights in the corners of the box on each side of the mirror, outside of the field of view of the camera. When the photo panel lamps are on, the instruments can easily be read through the one-way mirror.

The photo panel recording camera is a modified Bell and Howell, Model 71-K "Eyemo", 35-mm. motion picture camera. It is driven by a specially designed Ledex 8-position solenoid assembly. The system is designed to expose only one frame of film when the solenoid receives an electric pulse. It is actuated in the NHRP aircraft by pulses from the time-and-distance synchronizer unit of the digital recording system. One picture is taken simultaneously with the punching of each IBM card. The 100-foot rolls of film used provide about 1,500 usable frames.

The photo panel recording system was intended to back up the other more complex recording systems. Consequently, it displays nearly all of the flight data. Table 2 lists the data photographed and figures 6 and 7 show a diagram of the digital recording system and a photograph of the photo panel.

Table 2. - List of data measurements photographed on the photo panel

Parameter	Indicator	Signal source	Remarks
Aircraft heading	Component of N-1 system	N-1 compass	
Drift angle	Component of APN-82	AN/APN-82	
Indicated airspeed	Kollsman I.A.S. meter	Pitot and static lines	
*Sea surface temperature	DC voltmeter	Radiometer recorder	
Temperature	Synchro repeater	AMQ-7	
Run Number	Pixie lights	Master control panel	Numerically shaped filaments display selected numeral
Time	Clock	(Self contained)	
Time	Digital computer	Master timer	Seconds from beginning of digital record
*Radar picture number	Digital computer	0-15 camera	Permits comparison of radar pictures with contemporary data
Data or card counter	Digital computer	Time and distance unit	Permits direct comparison of cards and photo data
Latitude	Dual synchro repeater	latitude servo system	Two hands: Inner= minutes, outer = degrees
Wind direction and speed	Dual synchro repeater	Wind speed and direction servo systems	Two hands: Inner= kt., outer = degrees
Label Plaque			Used for flight and aircraft identification
*Cloud detection	Indicator light	Johnson-Williams liquid water content meter	Lights at a liquid water content value threshold

*Not recorded on B-47 aircraft

Table 2. (Con't)

Parameter	Indicator	Signal source	Remarks
Icing rate	Indicator lights	NACA icing rate recorder	Lights when icing collector is being de-iced
AN/APN-82 operation	Indicator lights A-D	AN/APN-82	Indicates power to system, system failures, and memory mode operation
Events	Indicator lights E-J	Meteorologist's station	Switched on by meteorologist to record time of events of special interest.
Altitude	Kollsman sensitive altimeter	Balanced static pressure system	
Absolute (radio) altitude	Dual synchro repeater	D-value computer	2 hands: Inner= hundreds of ft., outer= thousands of ft.
Temperature	Dual synchro repeater	AMQ-8	2 hands: Inner= temperature Outer= D-value
D-value	Dual synchro repeater	D-value computer	
True airspeed, groundspeed	Dual synchro repeater	AN/APN-82	2 hands: Inner= T.A.S., outer = groundspeed
Humidity	Microammeter	Infrared hygrometer	
Power voltage	Voltmeter	400-cycle power bus	
Power frequency	Vibrating reed frequency meter	400-cycle power bus	
*Manifold pressure engines 1 and 2 engines 3 and 4	(Extensions of normal aircraft instrument system using identical indicators)		
*RPM engines 1 and 2 engines 3 and 4			
** Percent RPM			

*Not recorded on B-47 aircraft

** Recorded only on B-47 aircraft

3. Heiland Oscillograph:. - Heiland Model 708C oscillographs are used in the two NHRP TB-50 aircraft to record the rapidly changing phenomena of particular importance to cloud physics research. An oscillograph is essentially an instrument designed to record rapid changes of voltage and current. The only moving parts of the signal circuits are the coils and mirrors of the moving-coil galvanometers. The data are recorded photographically on a rapidly-moving strip of photographic paper. The small galvanometer reflects a light beam on to the paper through a stationary system of mirrors and lenses. Small rotations of a coil result in large displacements of record trace.

An oscillograph will record without appreciable distortion only those events which have frequencies much less than the natural frequency of its galvanometers. The galvanometers used in the NHRP Heiland installations have a natural frequency of 40 cycles per second. They move the position of the light trace on the film one inch for each 4.45-microampere change of input current.

The Model 708C Heiland can accommodate 24 galvanometers - all of which can be used on the same record. The 12 galvanometers installed during the 1956 flight program were more than we had occasion to use.

The 200-foot rolls of recording paper are loaded into the oscillograph in light-tight supply drums. After use, they are removed in similar take-up drums. Each roll is used in approximately 1 1/2 hours at the 24 inches per minute paper speed employed.

A selector control on the front panel of the recorder can be used to change the recording rate to any one of four paper speeds having ratios of 1:1, 2:1, 4:1, or 8:1. Internal gear changes permit recording speeds from 0.03 to 144 inches per second.

Time lines are projected and recorded over the full width of the record each tenth of a second. Every tenth time line is somewhat wider. These lines are useful, but their timing is not coordinated with the master timer of the digital and photo panel systems. In order to achieve comparison of the records, one of the galvanometers is controlled by a stepping circuit in the time and distance synchronization unit. This circuit was designed to produce a time record trace in the form of 10-second pulses superimposed upon 1-minute steps.

The data reduction is facilitated by a trace identifier assembly in the recorder which briefly blanks the trace of each galvanometer in turn.

There are many other features designed into the Heiland 708C oscillograph. Only those features which have proved particularly useful to NHRP have been mentioned here. The information listed in table 3 is recorded by the Heiland in the NHRP TB-50 aircraft.

4. Meteorologist's Position in TB-50 Aircraft: - The meteorologist is stationed in the bombardier's position behind the plastic nose section of the fuselage. His field of vision extends approximately 45° each side of the flight track, down to about 50° below the horizontal, and up to the zenith. The nose section contains a special plastic work-table designed to facilitate preparation of flight logs. The time-lapse cloud camera is mounted beneath the table just behind the bomb sighting window. The AN/APS-23 radar repeater scope, the

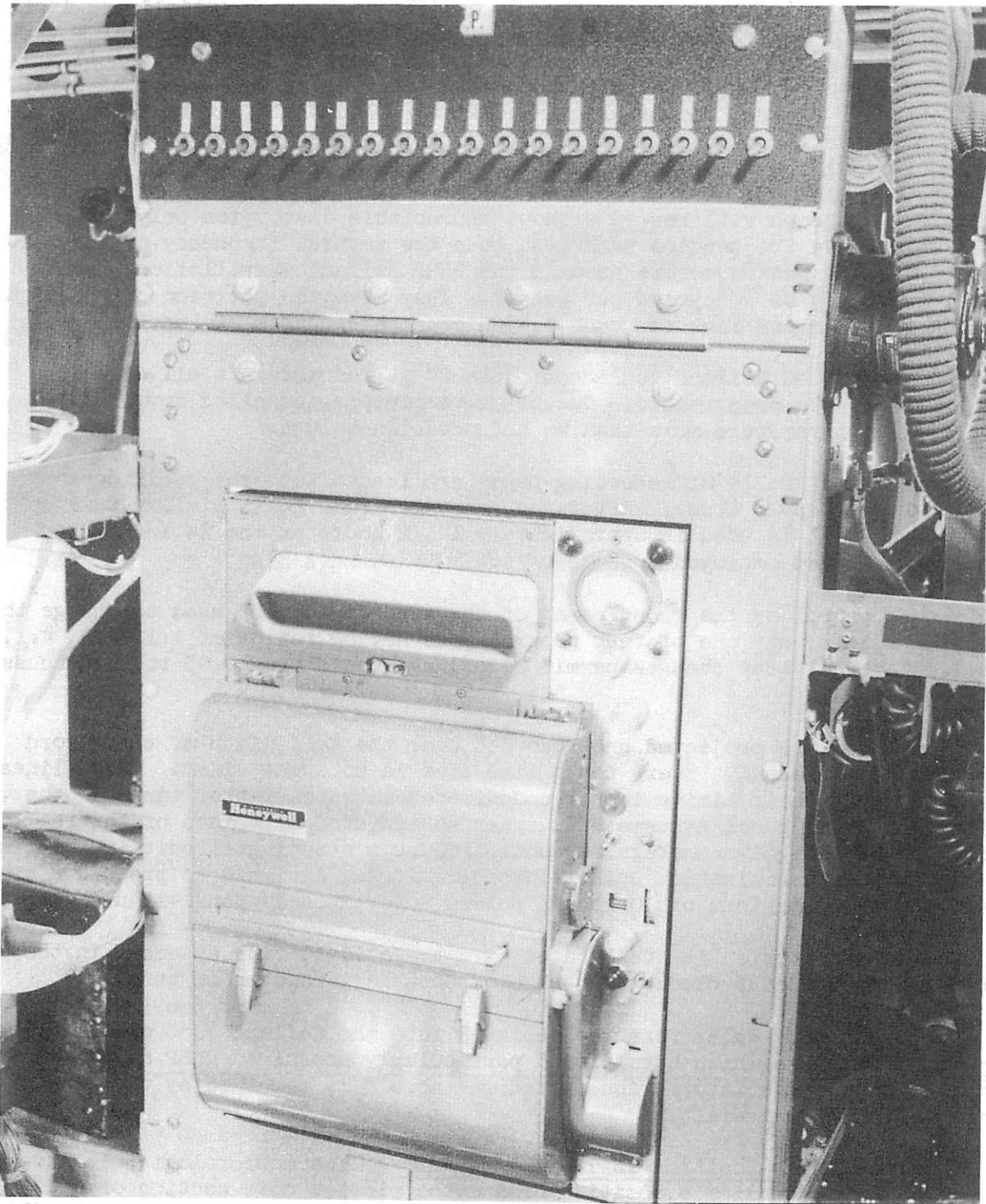


Figure 8. - Heiland oscillograph.

Table 3. - Information recorded by Heiland Model 708C oscillograph

Galvano-meter	Parameter	Signal source	Remarks
1	Liquid water content	Johnson-Williams hot-wire liquid water meter	
2	Cloud penetration signal	Cloud physicist	Cloud physicist closes switch when cloud is entered. Opens it upon leaving cloud
3,4,5,6	(Not used)		
7	Indicated airspeed	Statham indicated airspeed transducer	
8	Electric field	Electric field meter	
9	Cloud droplet sampler; slide exposure period	Cloud droplet sampler	
10	Humidity	Infrared hygrometer.	
11	Time	Master timer	Stepping circuits in T and D box create second pulses and 1-minute steps on time record trace
12	Temperature	Reverse-flow thermometer	

Table 4. - Information available on meteorologist's instrument panel

Parameter	Indicator	Signal source	Remarks
Latitude longitude	ID-389	AN/APN-82	
Radio altitude	Dual synchro repeater	D-value computer	2 hands: Inner=hundreds outer= thousands ft.
Wind speed and direction	Dual synchro repeater	AN/APN-82	2 hands: Inner= speed Outer = direction
Temperature and D-value	Dual synchro repeater	AMQ-8 D-value computer	2 hands: Inner= temp. Outer = D-value
Ground speed	ID-341/APN-81	AN/APN-82	
Humidity	Microammeter	Infrared hygrometer	
Time	Magnetic counter	Master timer	Seconds from beginning of digital record

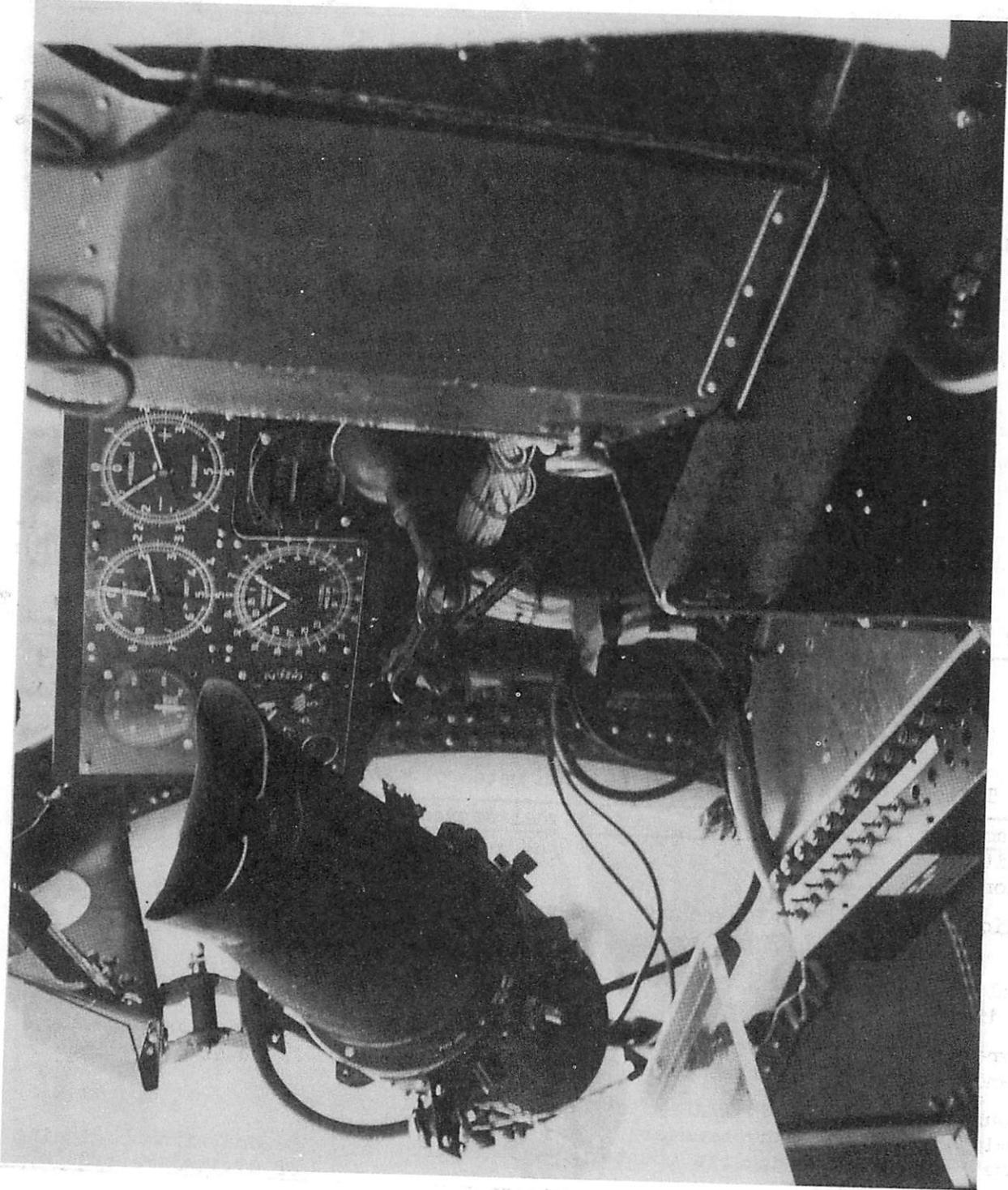


Figure 9. - Starboard side of meteorologist's station.

meteorologist's instrument panel, and the event signal switch box are mounted on the starboard side. The bombardier's instrument panel is on the port side. A dictaphone "Time Master" dictating machine is used by the meteorologist for voice recording.

The instruments on the meteorologist's panel (listed in table 4) reproduce the readings of identical indicators on the photo panel - with the exception of the ID-389 latitude and longitude indicator. Figure 9 is a view of the instruments at the right side of the meteorologist's station.

5. Cloud Cameras: - Two cloud cameras were used on the NHRP aircraft during the 1956 flight program.

The time-lapse cloud camera is a Kodak Cine Model K-100, 16-mm. camera, with an Angenieux 9.5-mm., f 2.2 lens. This is a very wide angle lens with 55° horizontal and 41° vertical field. The camera is equipped with a well-designed time-lapse mechanism developed by Dr. W. S. von Arx at the Woods Hole Oceanographic Institution. This unit is mounted on the camera and consists of a small 28V DC motor, and a scotch yoke mechanism which winds the camera and trips the shutter release for single frames. The time-lapse period is approximately 1.5 seconds. 100-foot rolls of 16-mm. Kodachrome film are adequate for about 1 3/4 hours' operation.

The meteorologist was also furnished with a standard Cine-Kodak Royal magazine camera with 50-foot 16-mm. Kodachrome magazines, and a Weston exposure meter. This camera was equipped with a Kodak Cine Ektor 15-mm. f 2.5, wide-angle lens. The field of view of the lens is about 26° in the vertical and 35° in the horizontal.

II. LABORATORY AND FLIGHT CALIBRATIONS

A. TYPES OF CALIBRATIONS

The following types of calibrations have been made by the National Hurricane Research Project: (1) Laboratory calibrations of individual instruments; and (2) Flight calibrations, including position errors of the aircraft pitot-static systems, true airspeed calibrations of AN/APN-82 systems, and comparison of the vortex thermometer temperatures at various airspeeds and with a radiosonde sounding.

Calibrations were furnished to NHRP by the agencies supplying the infrared hygrometers and the NACA icing rate recorders.

The data collected by the NACA VGH recorders, the WADC system, and the cloud physics equipment are not being processed by NHRP, and calibrations of these instruments do not appear in this report.

B. DISCUSSIONS OF METHODS AND RESULTS

1. Laboratory Calibrations. - Laboratory calibrations of the pressure altimeters and indicated airspeed meters were performed at the Palm Beach Air Force Base, Instruments Laboratory, to determine the necessary static corrections for the individual instruments.

Altimeters were calibrated against a mercurial barometer. Graphs of error versus pressure altitude were drawn for both ascent and descent and are shown in figures 10 through 16. The spread between these curves is due to hysteresis, and to friction and looseness in the linkages. The mean of the simulated ascent and descent has been plotted and can be used to approximate average altimeter characteristics under flight conditions.

The pressure-altitude systems of the D-Value computers were calibrated in the same manner as the altimeters. The pressure-altitude versus error curves for ascent and descent show very little spread. The great non-linearity of the curves is a characteristic of the electrical output of the synchrotels. Figures 17 and 18 show these calibration curves.

The airspeed indicators were calibrated by measuring a pressure difference between the static and the pitot lines by use of a water manometer graduated in units of speed. Calibration curves of airspeed versus error are shown in figures 19 and 20.

The sea surface radiometer was calibrated by direct comparison of its readings with the measured temperature of water in a pan held beneath the instrument. When the water temperature is equal to the temperature of the reference black body the instrument reads zero. Figure 21 shows the calibration curve of sea surface temperature versus instrument readings. This calibration was valid for only a few weeks because of subsequent efforts to improve the instrument and is presented only as an example of several calibrations performed on the radiometer.

2. Position Error Calibrations. - The determination of the pressure-altitude of an airplane is compromised by the distortion of the air pressure field near the aircraft caused by the motion of the aircraft. The difference between the true ambient air pressure and the pressure at the static pressure-measuring-system ports is a function of the airspeed and angle of attack of the airplane. This information is further dependent upon the location or position on the aircraft of the static ports. These "position errors" of the pressure-altitude measurements must be determined for various airspeeds and angles of attack.

a. Airspeed method. - The pressure-altitude "position errors" can be calculated from the results of flight calibrations of the airspeed measurements errors. The common airspeed indicators measure the difference between the pitot tube pressures and the static port pressures and express these differences in terms of airspeed at sea level. The pressure in the pitot tube is the total pressure head of the streamline relative to the airplane. This total pressure is not strongly affected by the disturbance in the local pressure field caused by the motion of the plane if the pitot orifice is located forward of the propellers. The position errors of the pitot tube are usually considered negligible compared to the position errors of the static ports. Although there was no immediate meteorological reason for calibrating airspeed, the airspeed indicators have a much greater degree of precision than altimeters and permit closer determination of the position errors. The altitude position errors were calculated by assuming first that the entire airspeed position error is caused by static pressure error, and then expressing these static pressure errors in terms of altitude errors in the standard atmosphere.

Figure 10

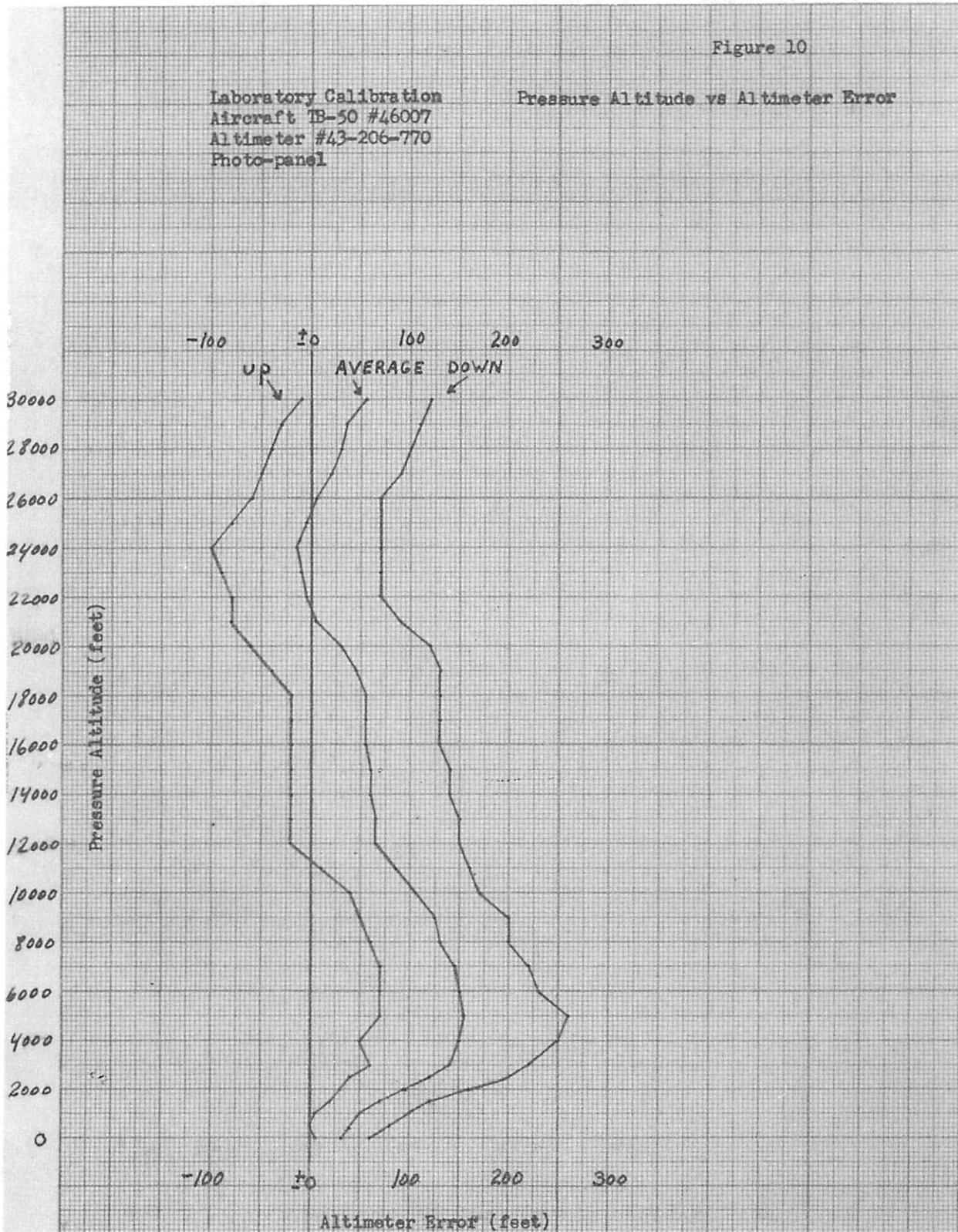


Figure 11

Laboratory Calibration
 Aircraft TB-50 #46007
 Altimeter #43-127-121
 Meteorologist

Pressure Altitude vs Altimeter Error

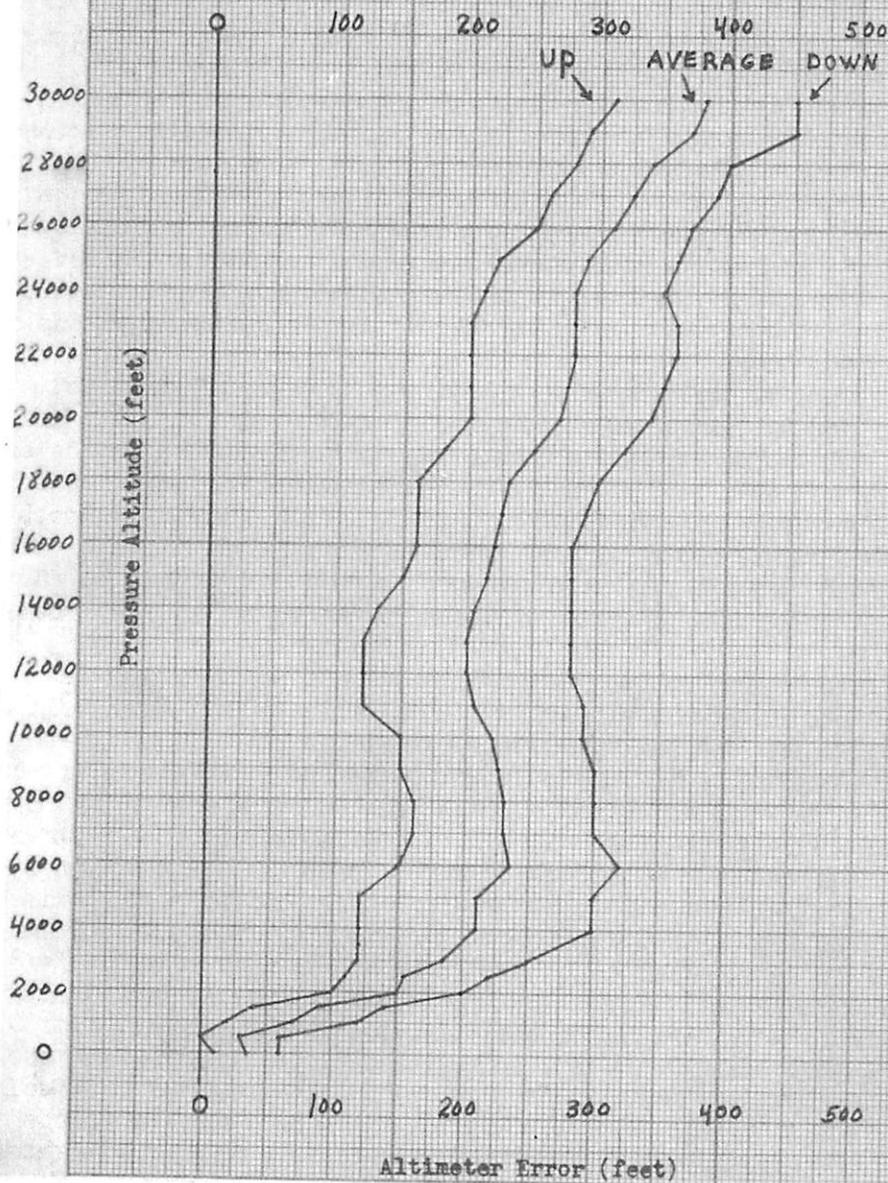


Figure 12

Laboratory Calibration
Aircraft TB-50 #46007
Altimeter #32-051-32767
Infra-red Hygrometer

Pressure Altitude vs Altimeter Error

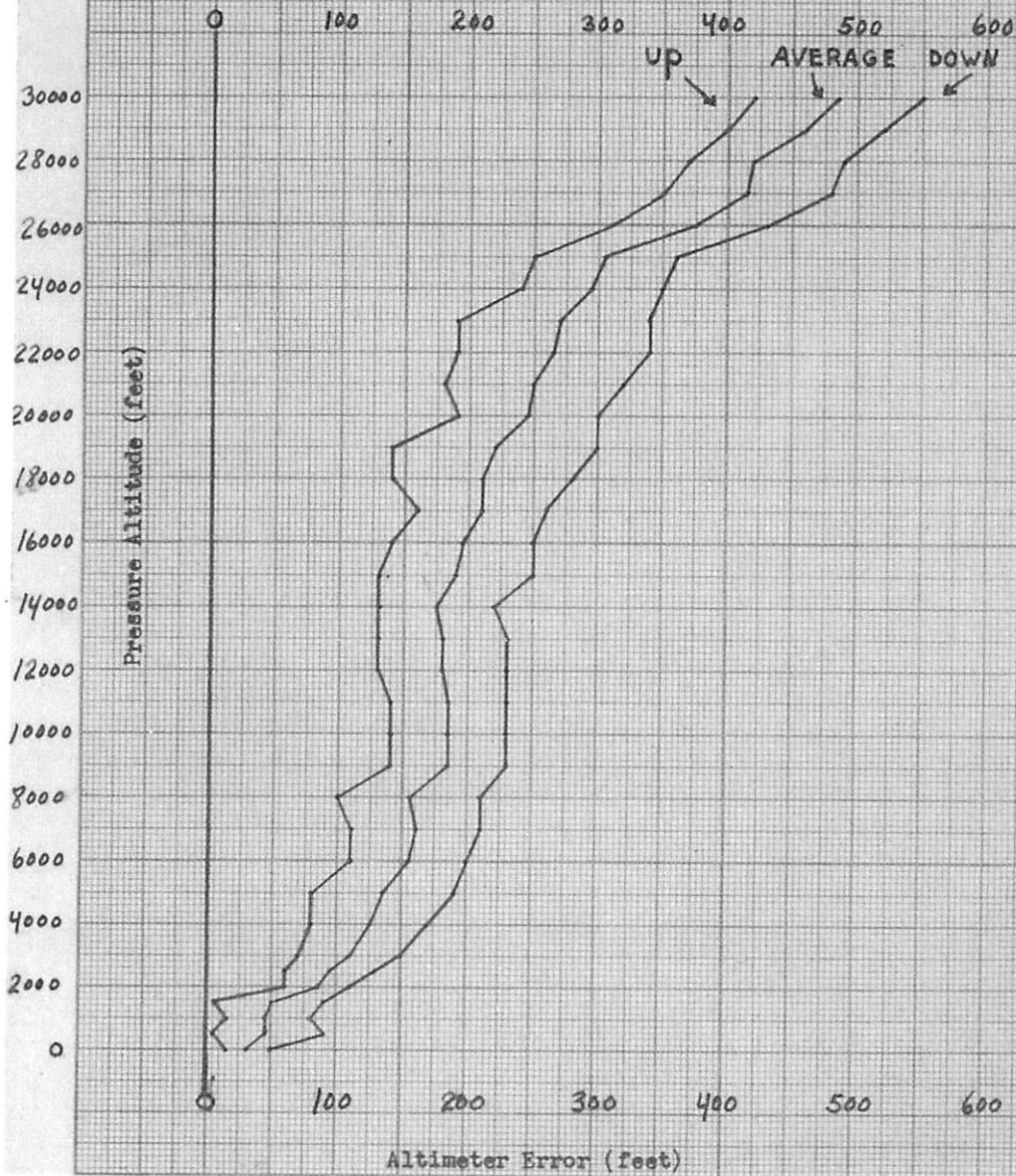


Figure 13

Laboratory Calibration
 Aircraft TB-50 #46032
 Altimeter #32766
 Photo-panel

Pressure Altitude vs Altimeter Error

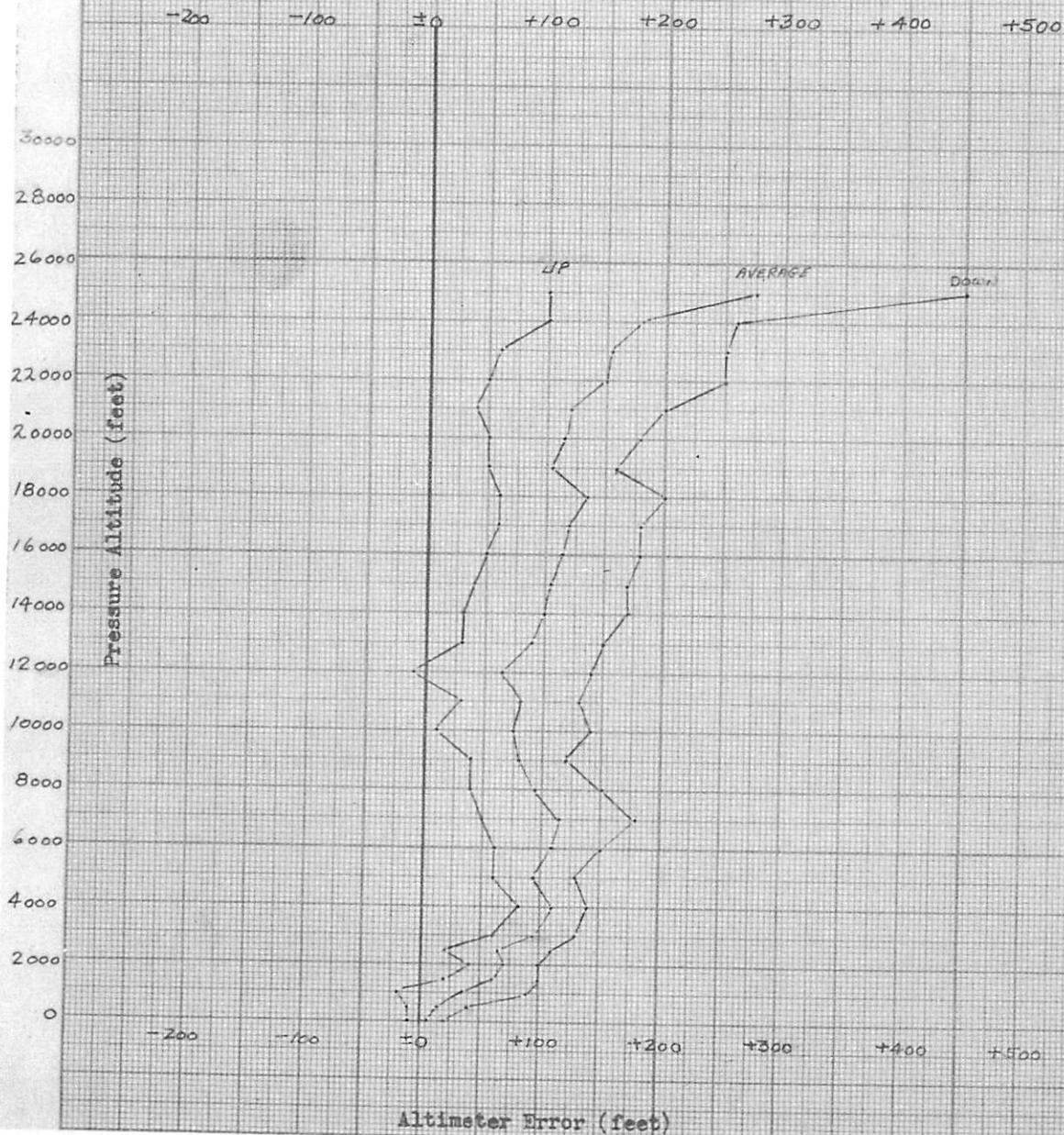


Figure 14

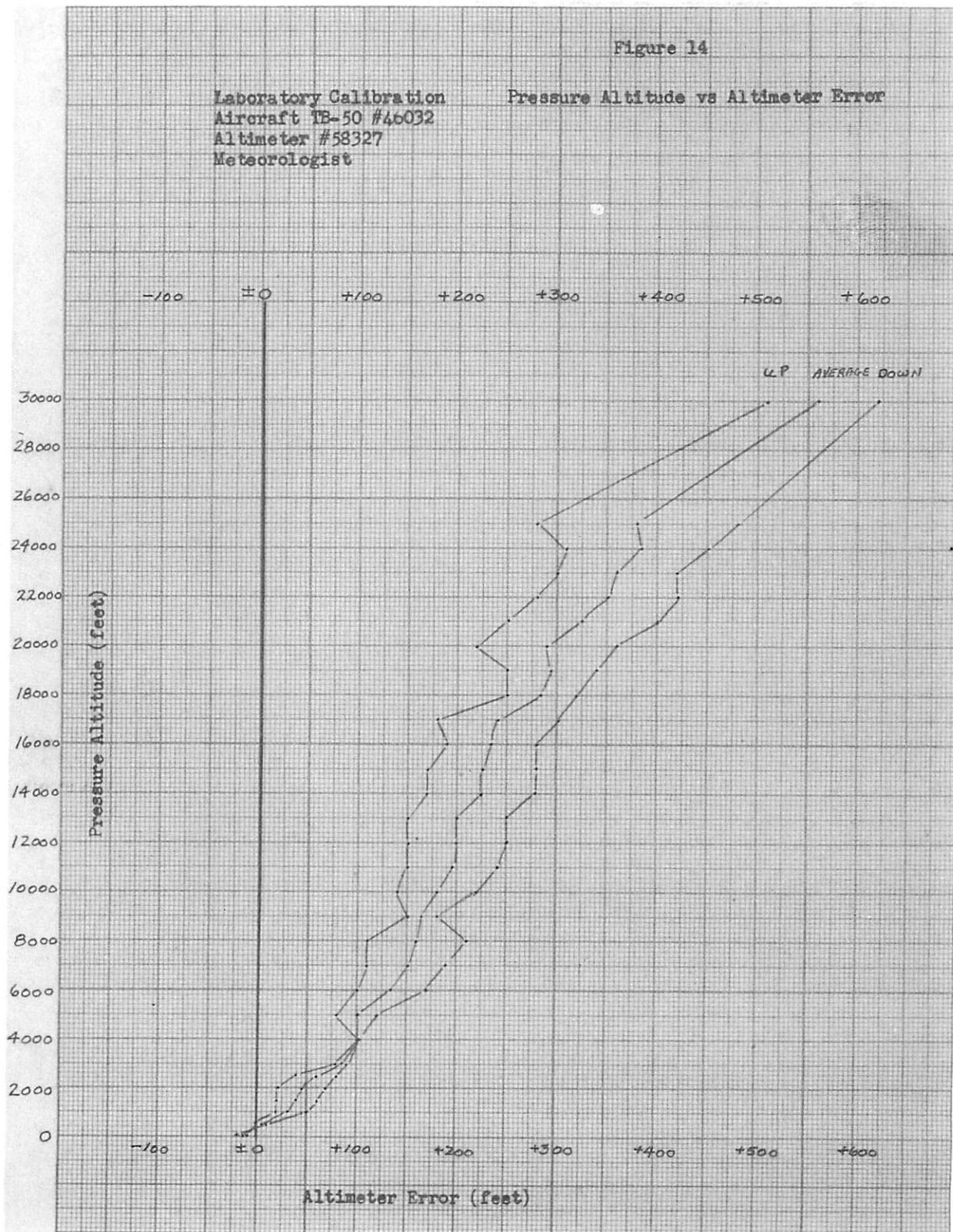


Figure 15

Laboratory Calibration
 Aircraft TB-50 #46032
 Altimeter #16614
 Infra-red Hygrometer

Pressure Altitude vs Altimeter Error

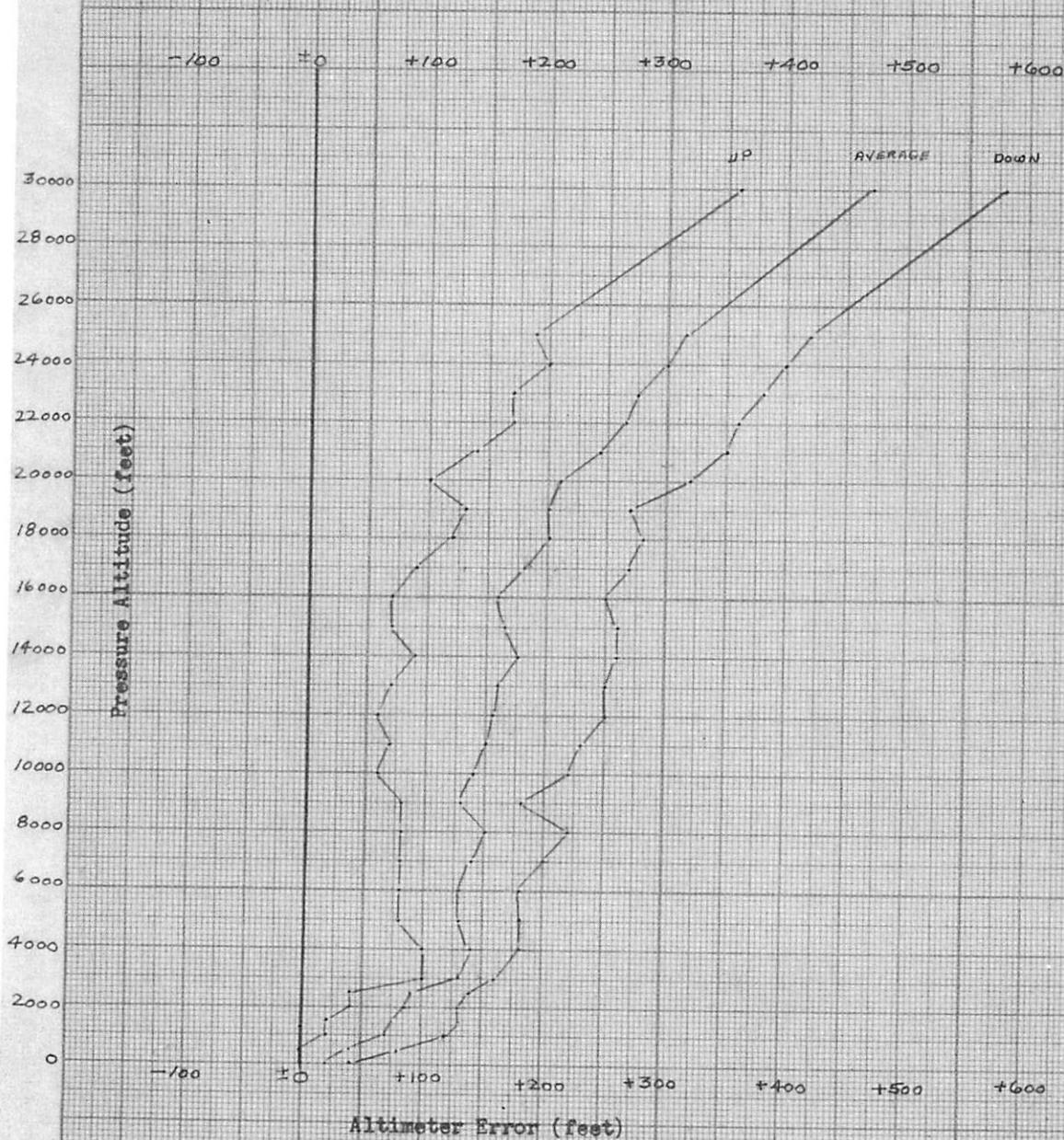
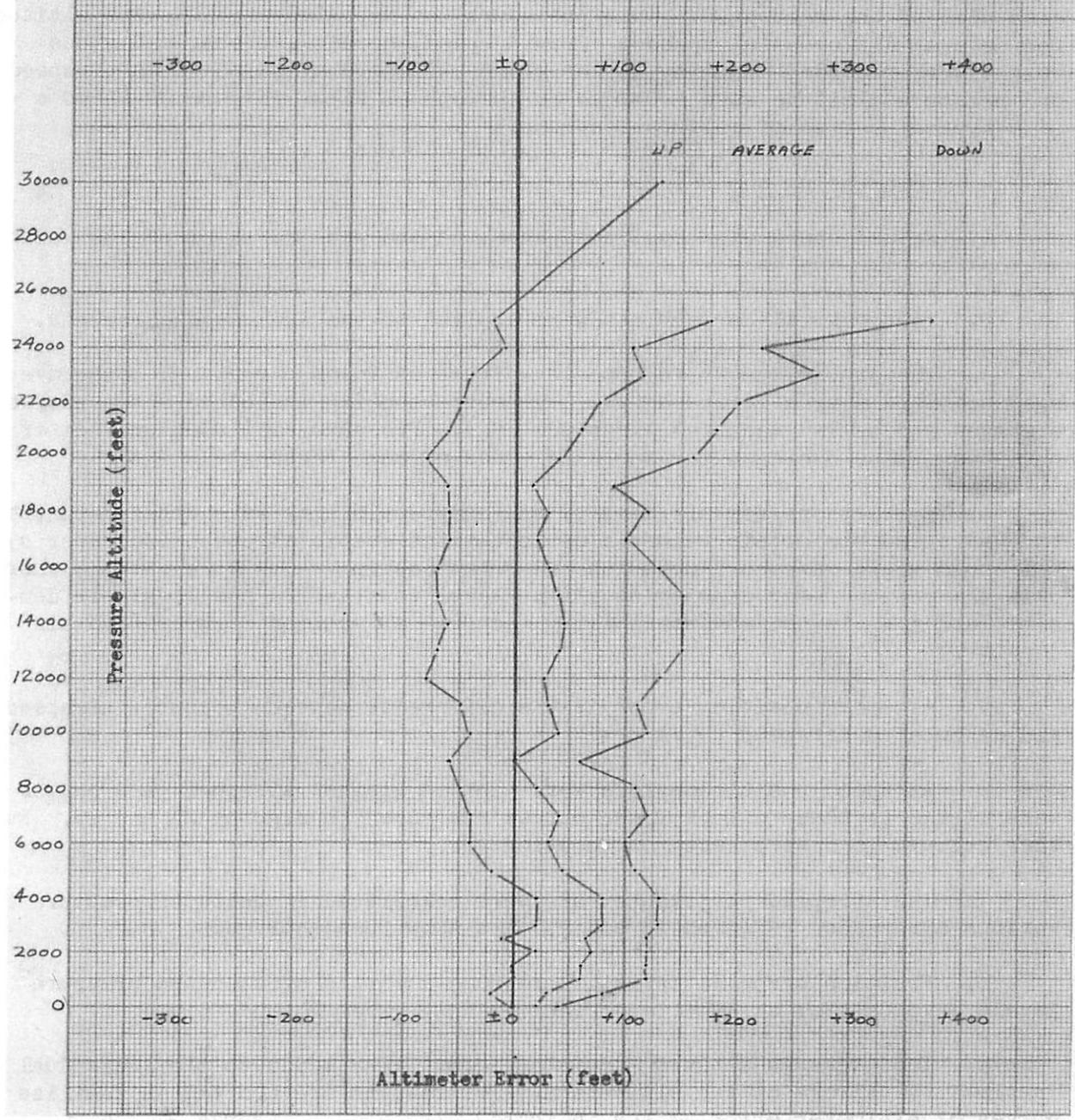


Figure 16

Laboratory Calibration
Aircraft TB-50 #46032
Altimeter #19878
Spare

Pressure Altitude vs Altimeter Error



Outline of method used by NHRP: True airspeeds were calculated from ground speeds measured by the AN/APN-82. Using formulae applying to airspeed measurement from pitot-static pressures, these true airspeeds were converted to the values a perfect pitot-static indicated airspeed installation would yield. The difference between this calculated airspeed and the actual indicated airspeed position error has been assumed to be the equivalent of a pressure error at the static ports. Every altimeter on the same pitot-static system was corrected by converting airspeed position error to pressure-altitude position error.

Calibration flights: The airplane flew a rectangular path maintaining constant pressure altitude and indicated airspeed. Heading was constant for each side of the rectangle. This procedure was repeated at different altitudes for several different airspeeds. Ground speed, heading, track, and gross weight were recorded manually on the plane. Temperature, indicated airspeed, and pressure-altitude were recorded on photopanel film. Figure 22 shows a map of a typical series of calibration runs.

Processing the raw data:

1. Ground speed was considered absolute and was the reference on which the calibration was based.
2. Instrumental corrections were applied to the indicated airspeeds.
3. The ground speeds in opposing direction in each rectangle were averaged to yield a true airspeed (V). The corresponding indicated airspeeds were averaged and called measured airspeeds (V_m). Pressure-altitudes and temperatures were also averaged for opposing sides of each rectangle.
4. Corrections for air density and compressibility were applied to the true airspeeds to obtain values a perfect pitot-static airspeed indicator system would yield in accordance with the relationship $V_{cal} = V\sqrt{\sigma} + \Delta V_c$, where σ is the ratio of air density at flight level to standard sea level air density, and ΔV_c is the compressibility factor - a function of speed and air density.
5. Airspeed position error is the difference between measured airspeed and calculated airspeed ($\Delta V_{pe} = V_m - V_{cal}$).
6. Airspeed position errors were plotted against airspeed, and curves were fitted to these data. These curves are shown in figures 23 and 25. Further calculations were based on these curves.
7. The airspeed position errors were calculated in units of pressure for various airspeeds. Figures 23 and 25 also show these curves.
8. Position error in terms of pressure-altitude at standard pressure levels is presented as families of curves in figures 24 and 26.
9. The pressure-altitude position errors were added to the individual instrumental errors of the altimeters. The results are plotted as families of curves of altimeter error versus indicated airspeed in figures 24 and 26.

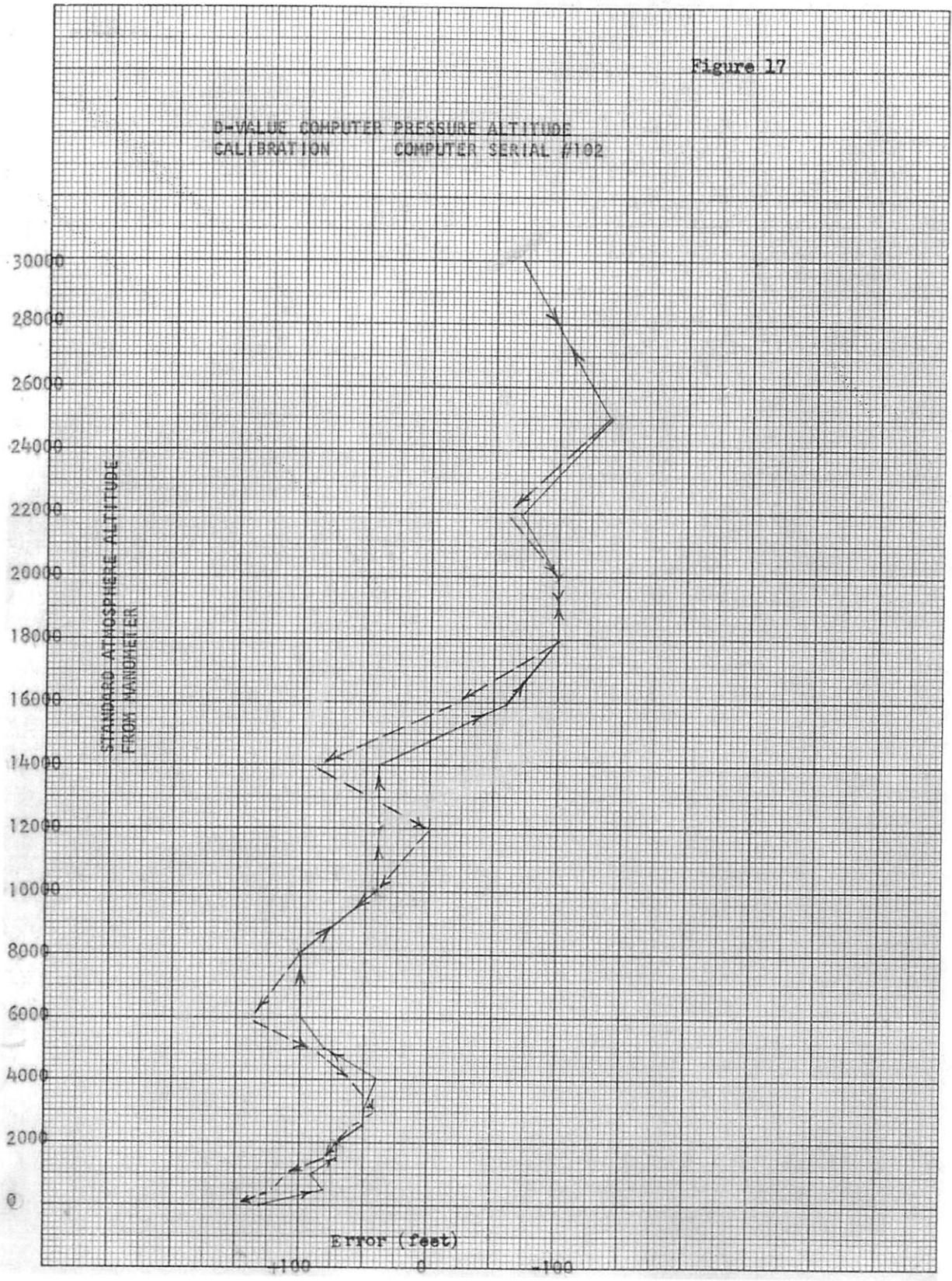


Figure 18

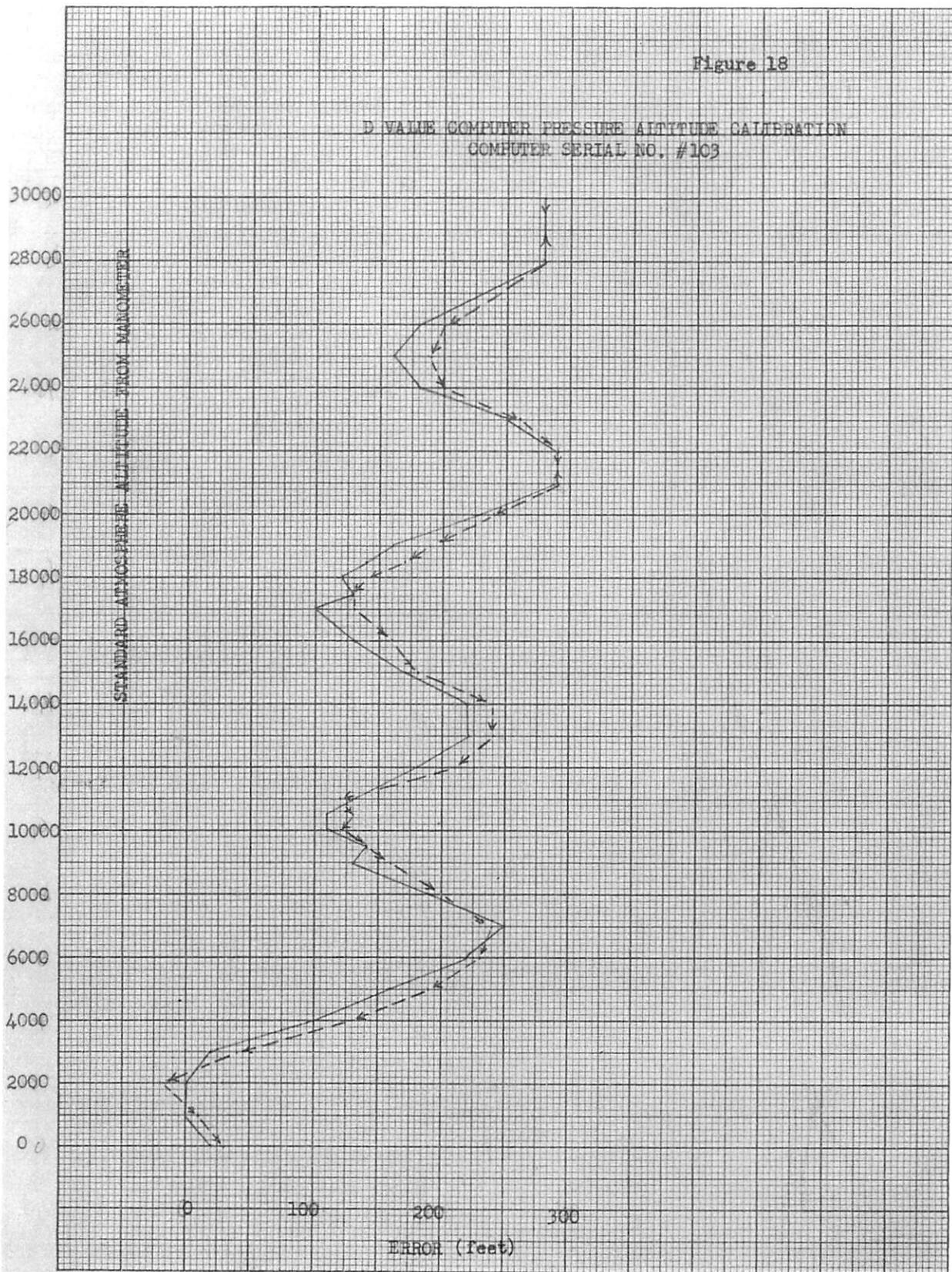


Figure 19

Laboratory Calibration Air Speed Indicator Error
 Aircraft B-50 #46007
 Airspeed Indicator #6392
 Photo-panel

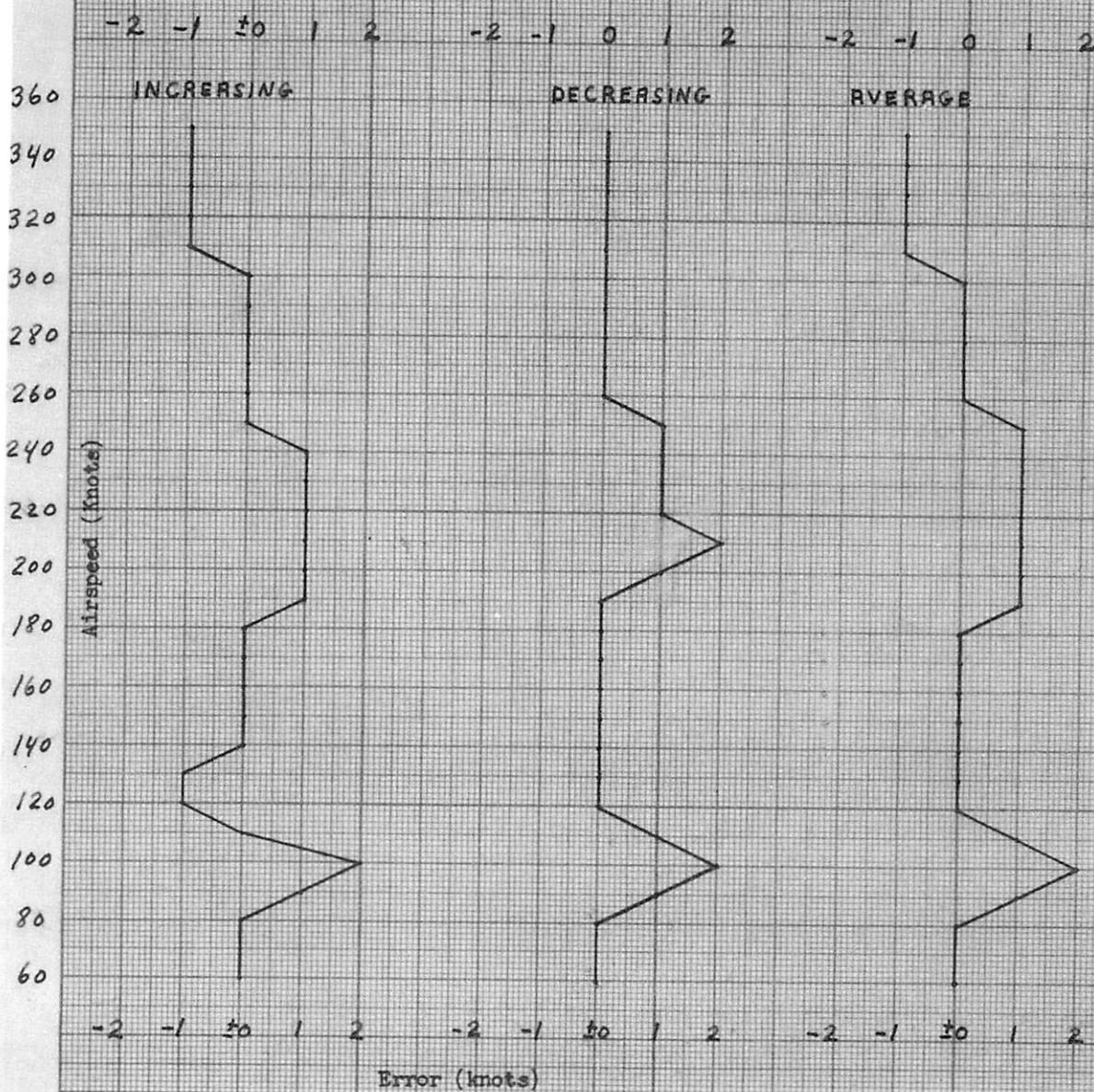
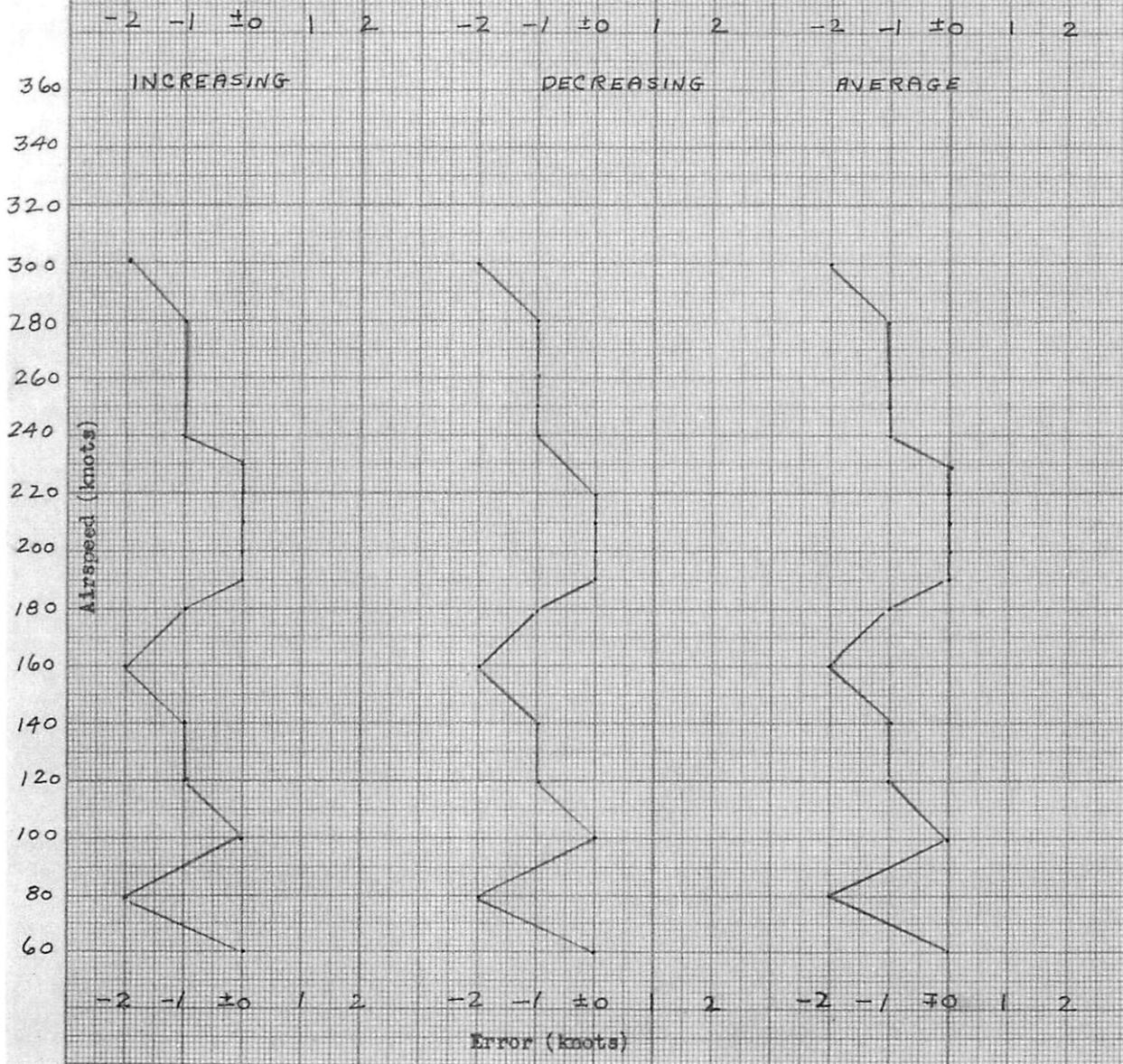


Figure 20

Laboratory Calibration Airspeed Indicator Error
 Aircraft TB-50 #46032
 Airspeed Indicator #537-6394
 Photo-panel



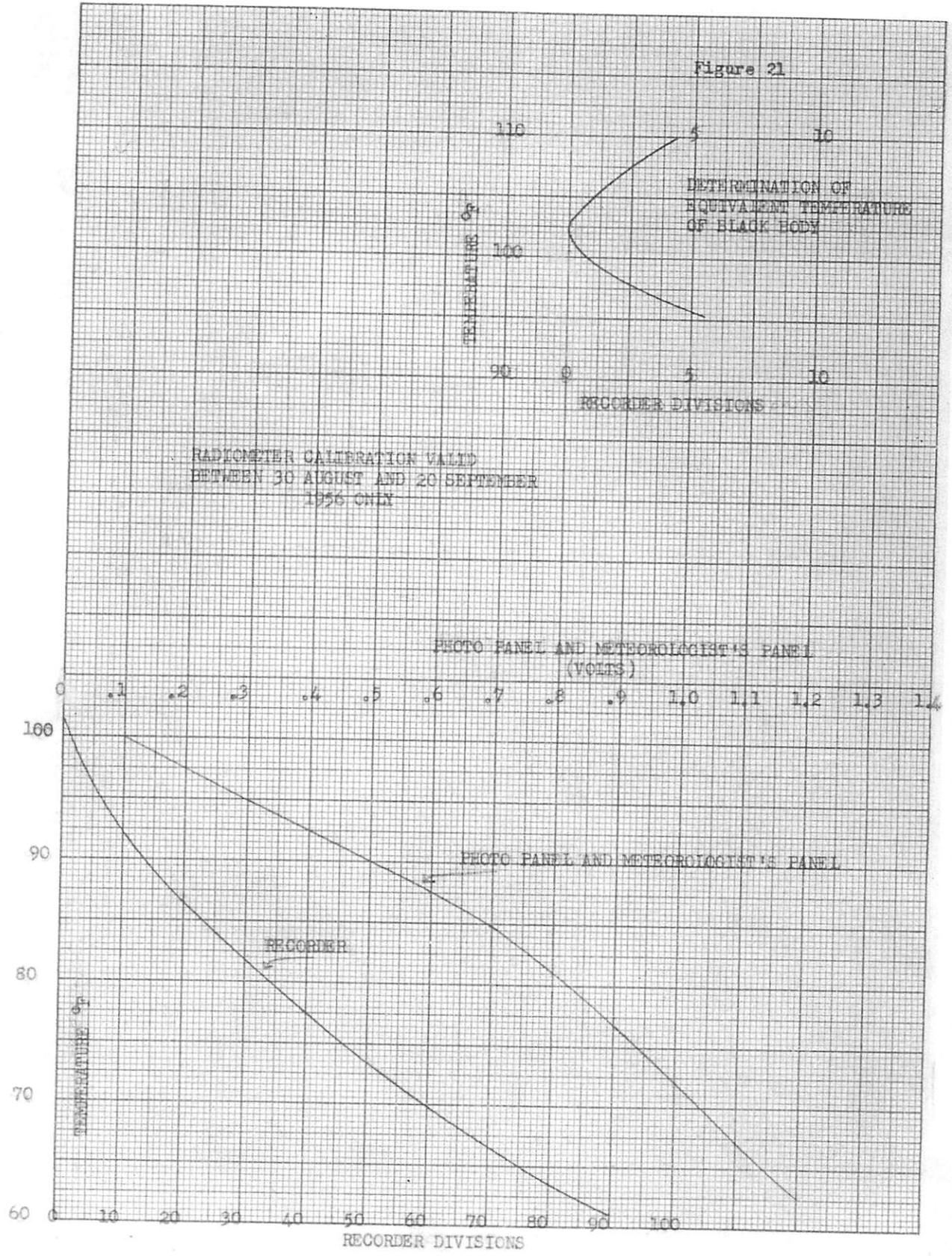
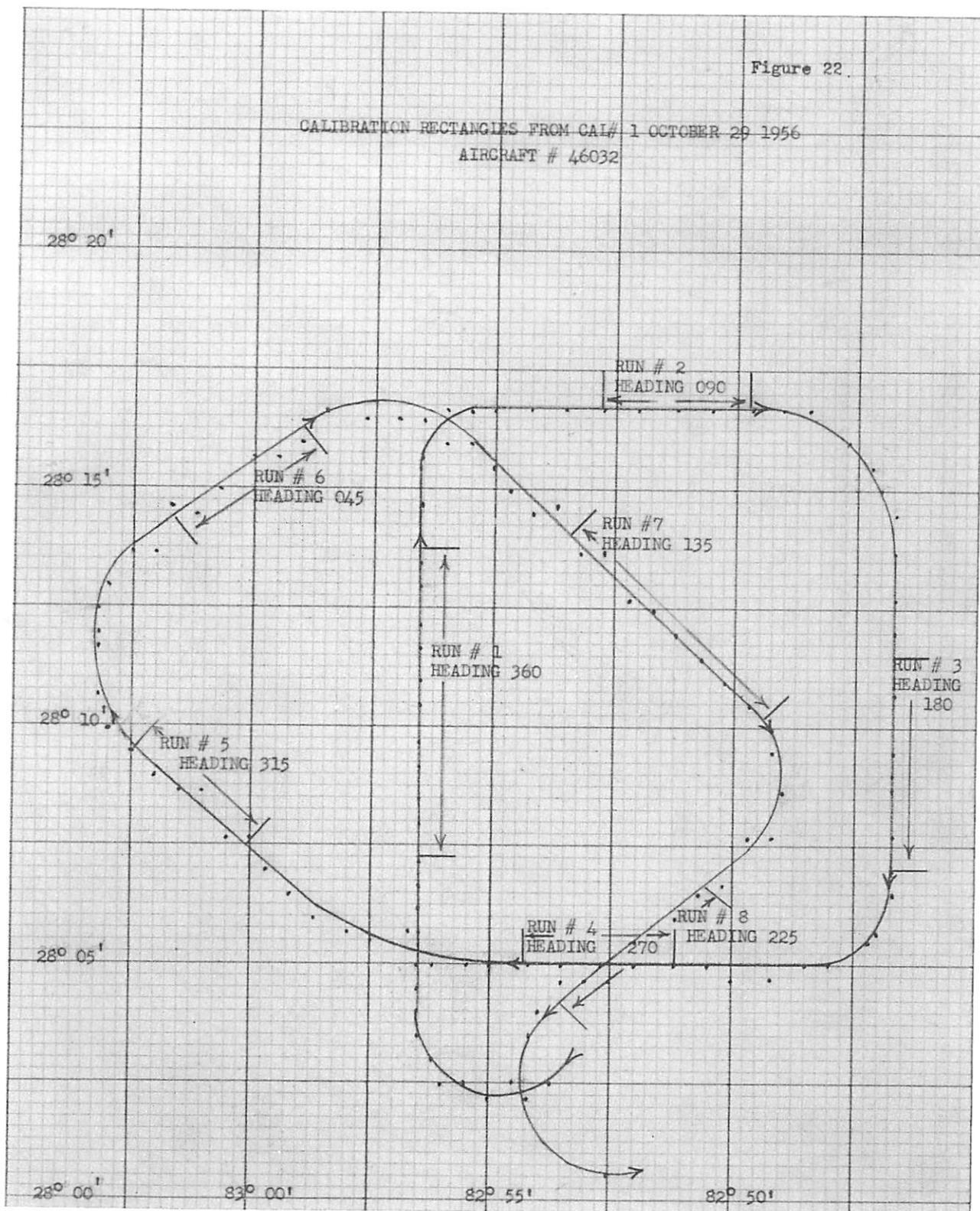


Figure 22.

CALIBRATION RECTANGLES FROM CAL# 1 OCTOBER 29 1956
 AIRCRAFT # 46032



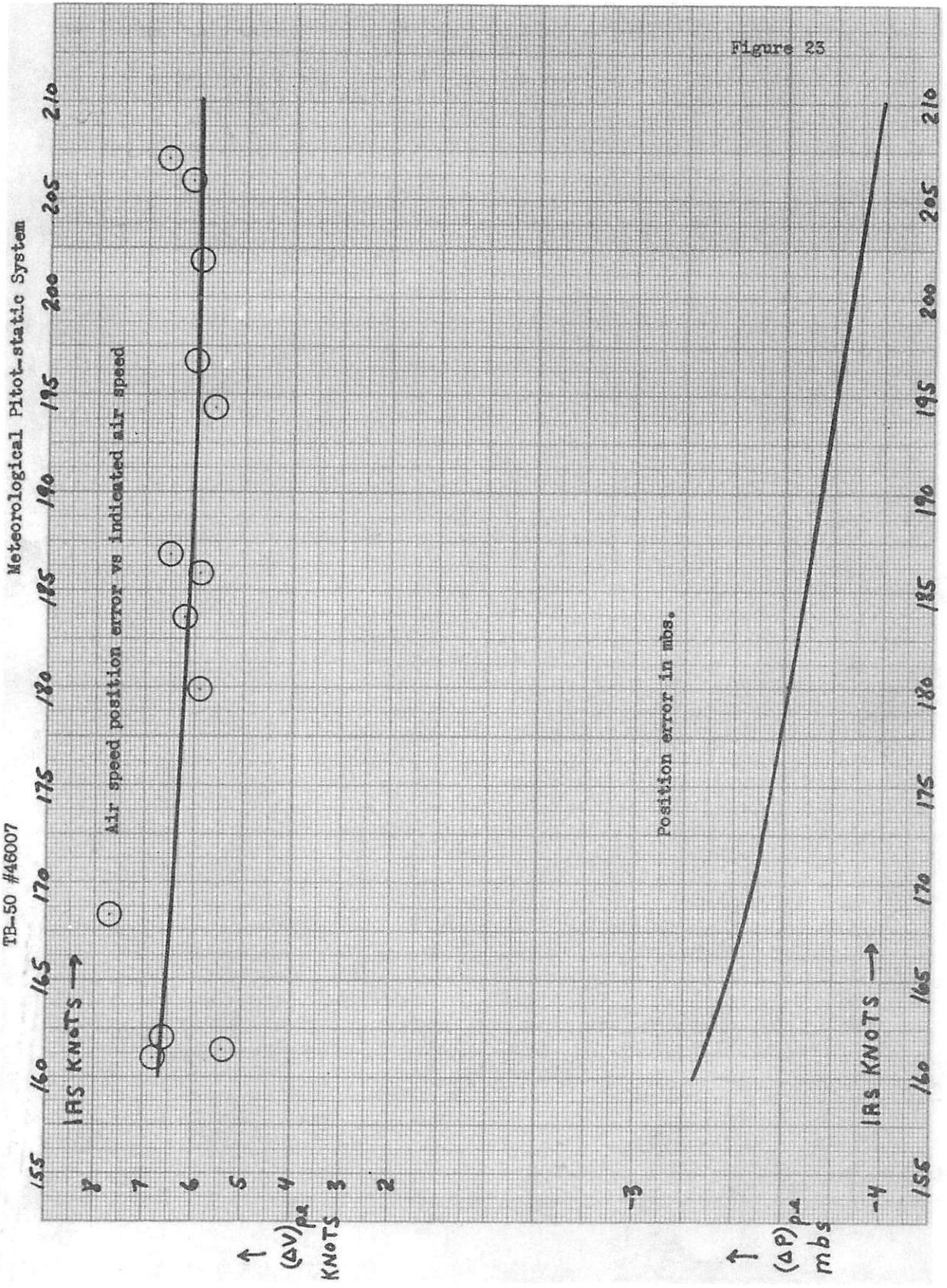
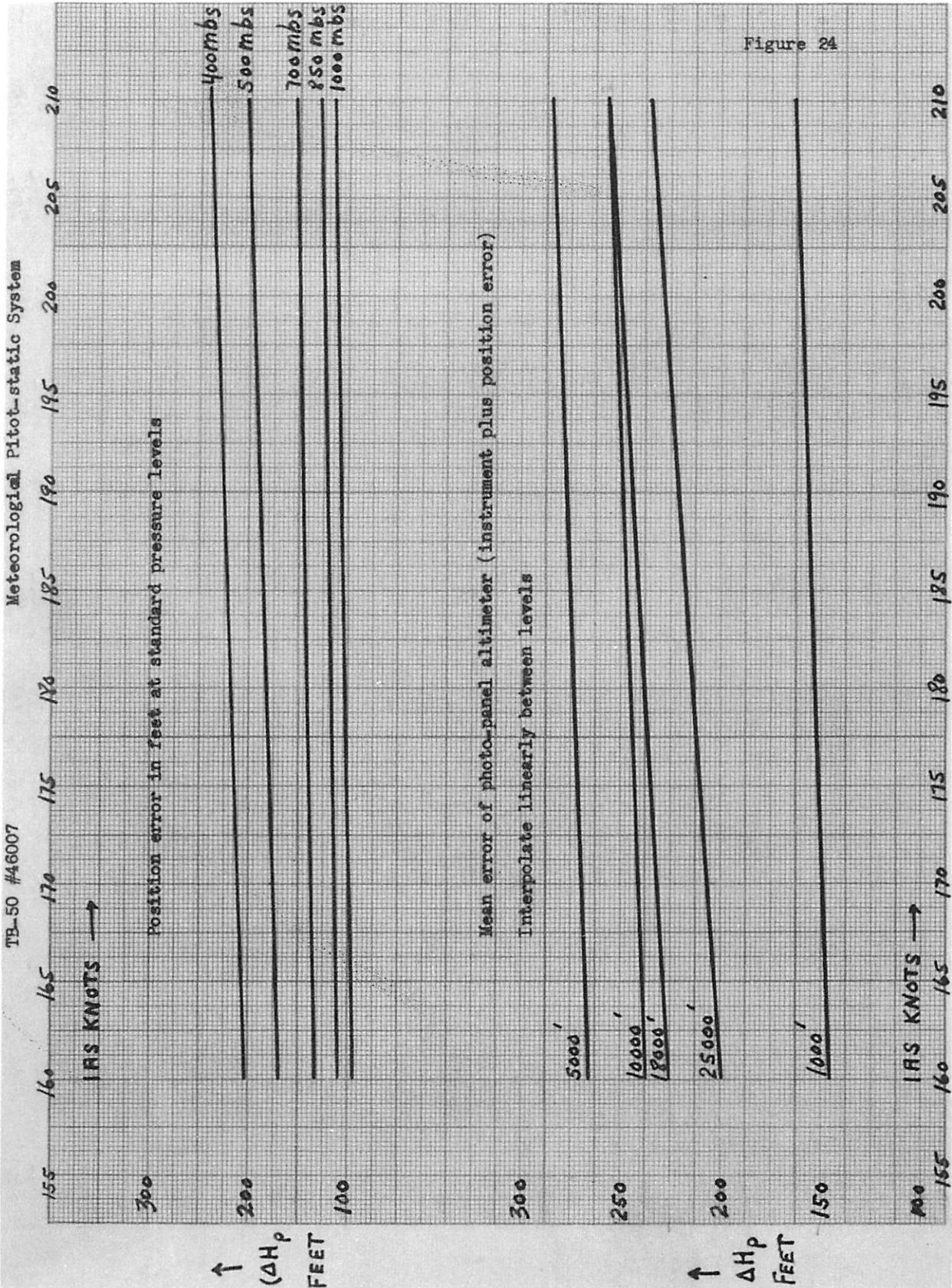


Figure 23



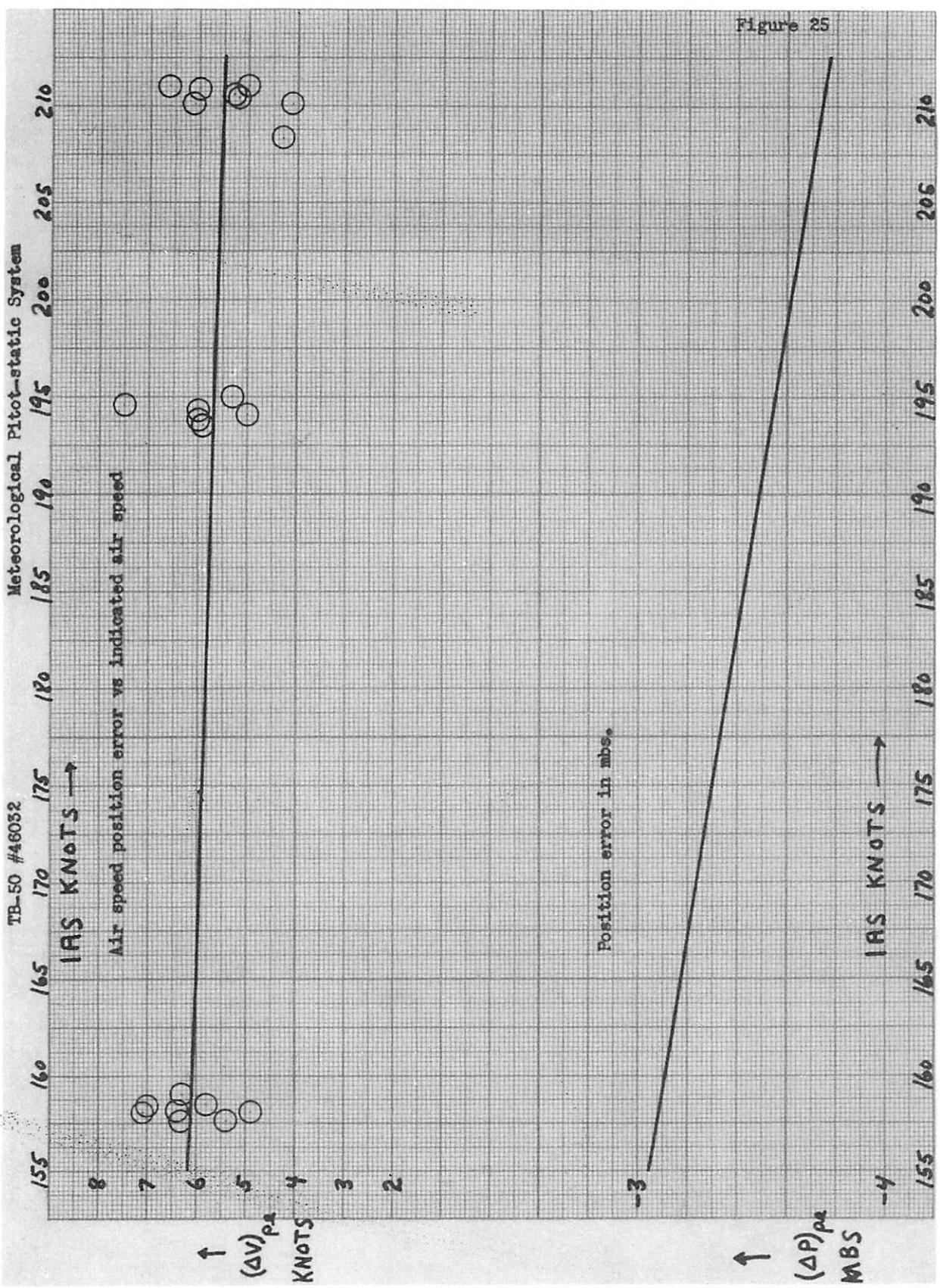
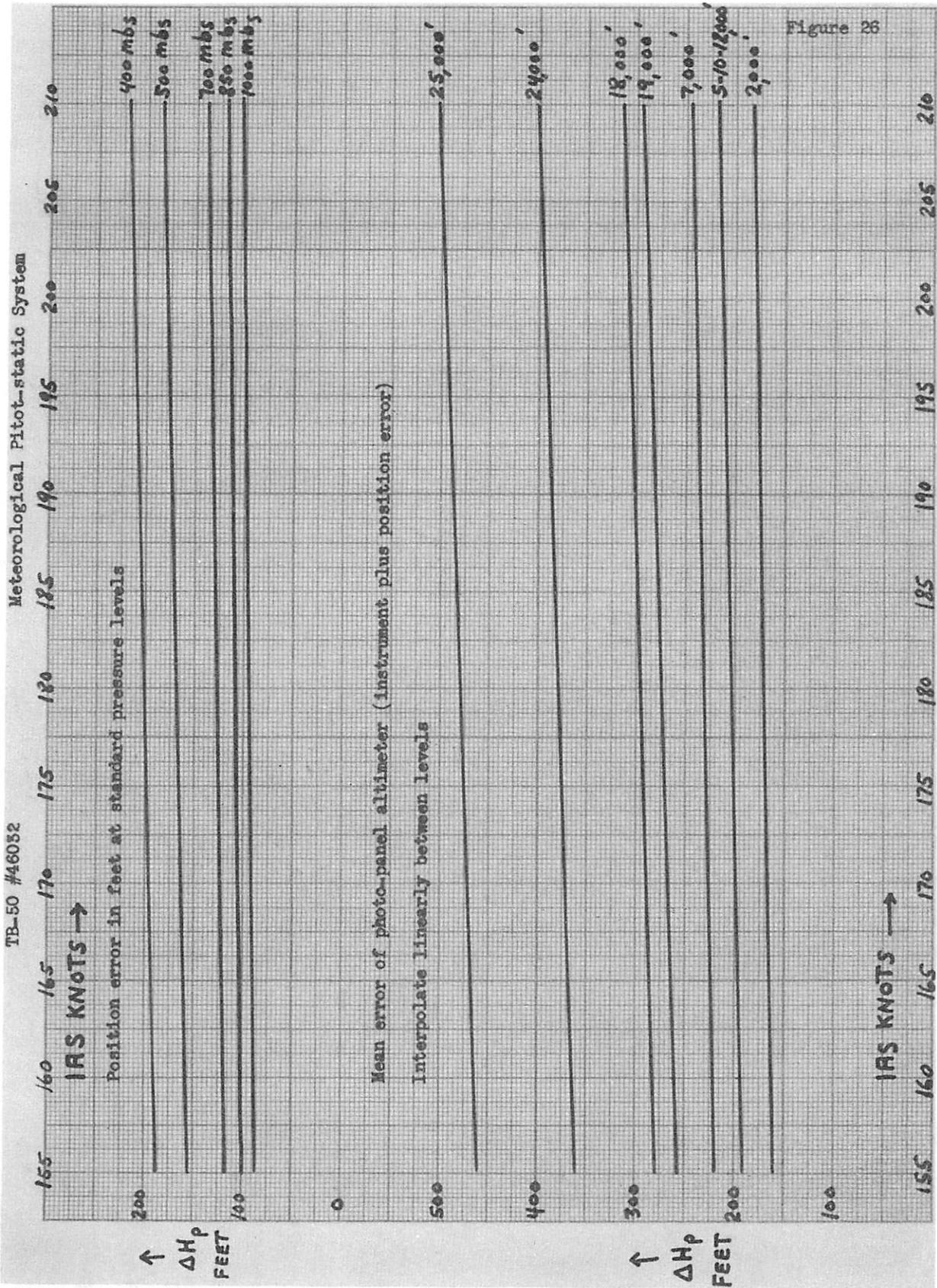
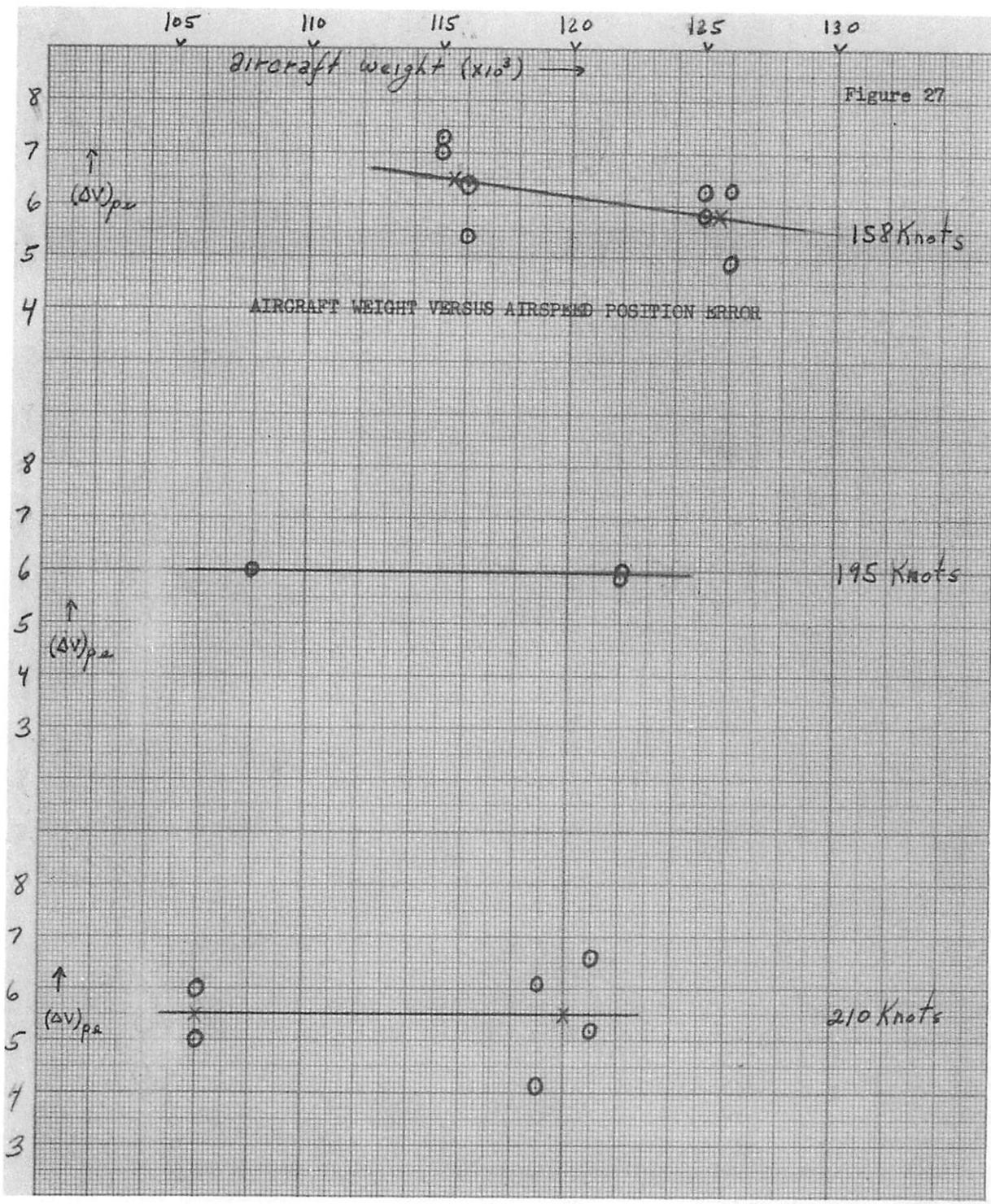


Figure 25



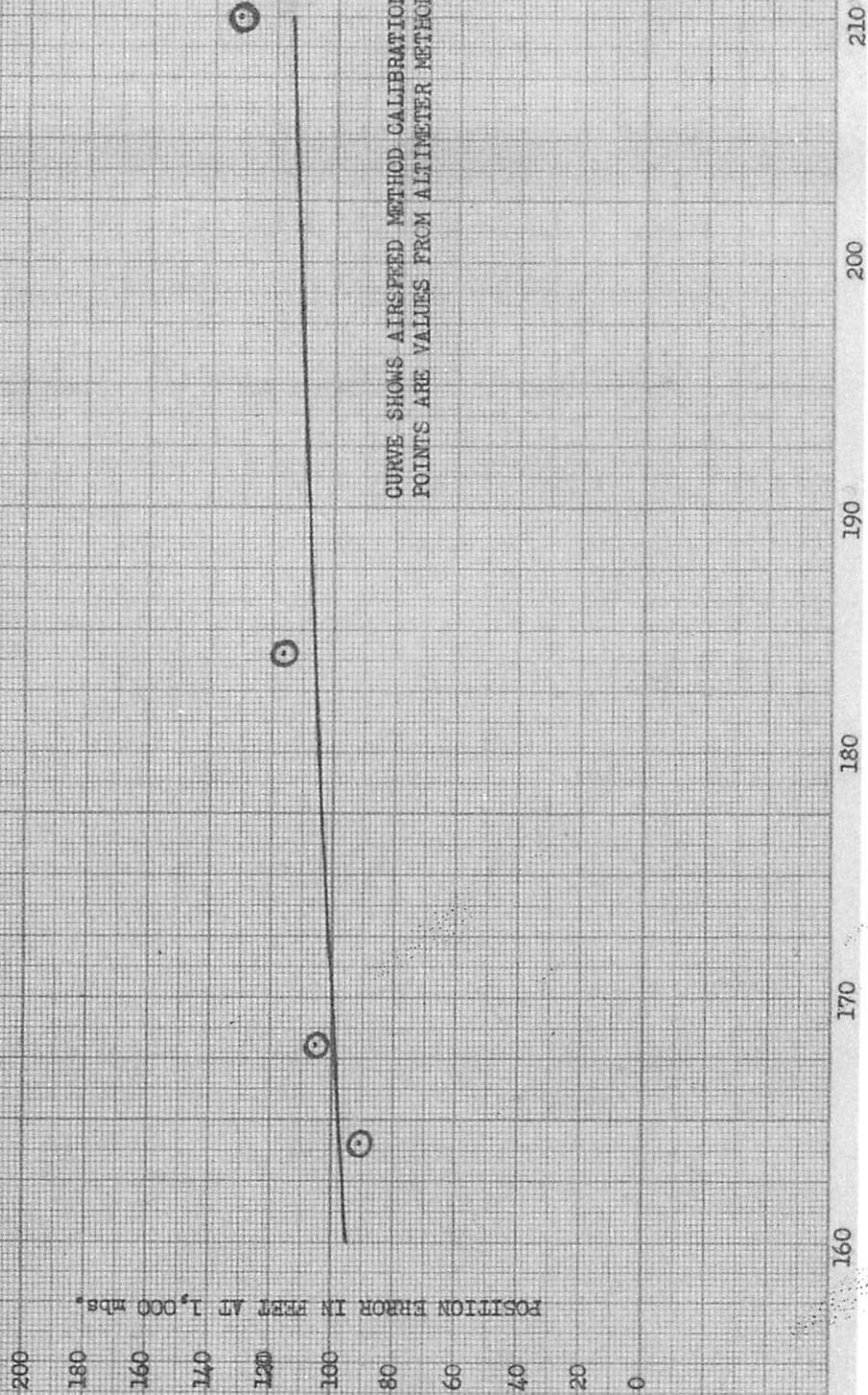


COMPARISON OF ALTIMETER METHOD AND AIRSPEED METHODS
 OF POSITION ERROR CALIBRATION. PHOTO PANEL ALTIMETER
 (TB-50, #46007)

POSITION ERROR IN FEET AT 1,000 mps.

CURVE SHOWS AIRSPEED METHOD CALIBRATION.
 POINTS ARE VALUES FROM ALTIMETER METHOD.

Figure 28



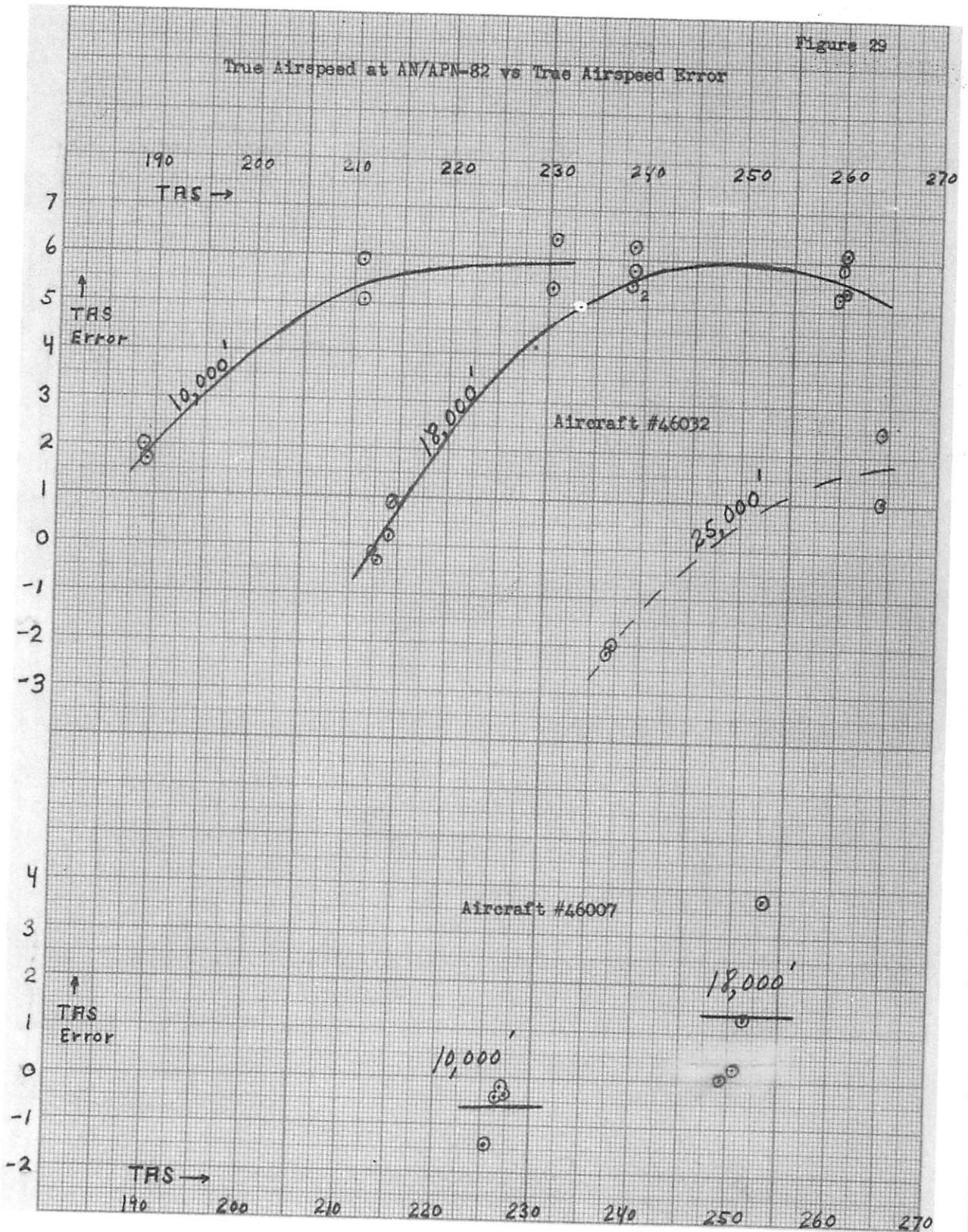


Figure 30

AMQ-8 Vortex Thermometer
 Temperature deviations from average for a series of runs
 as a function of speed

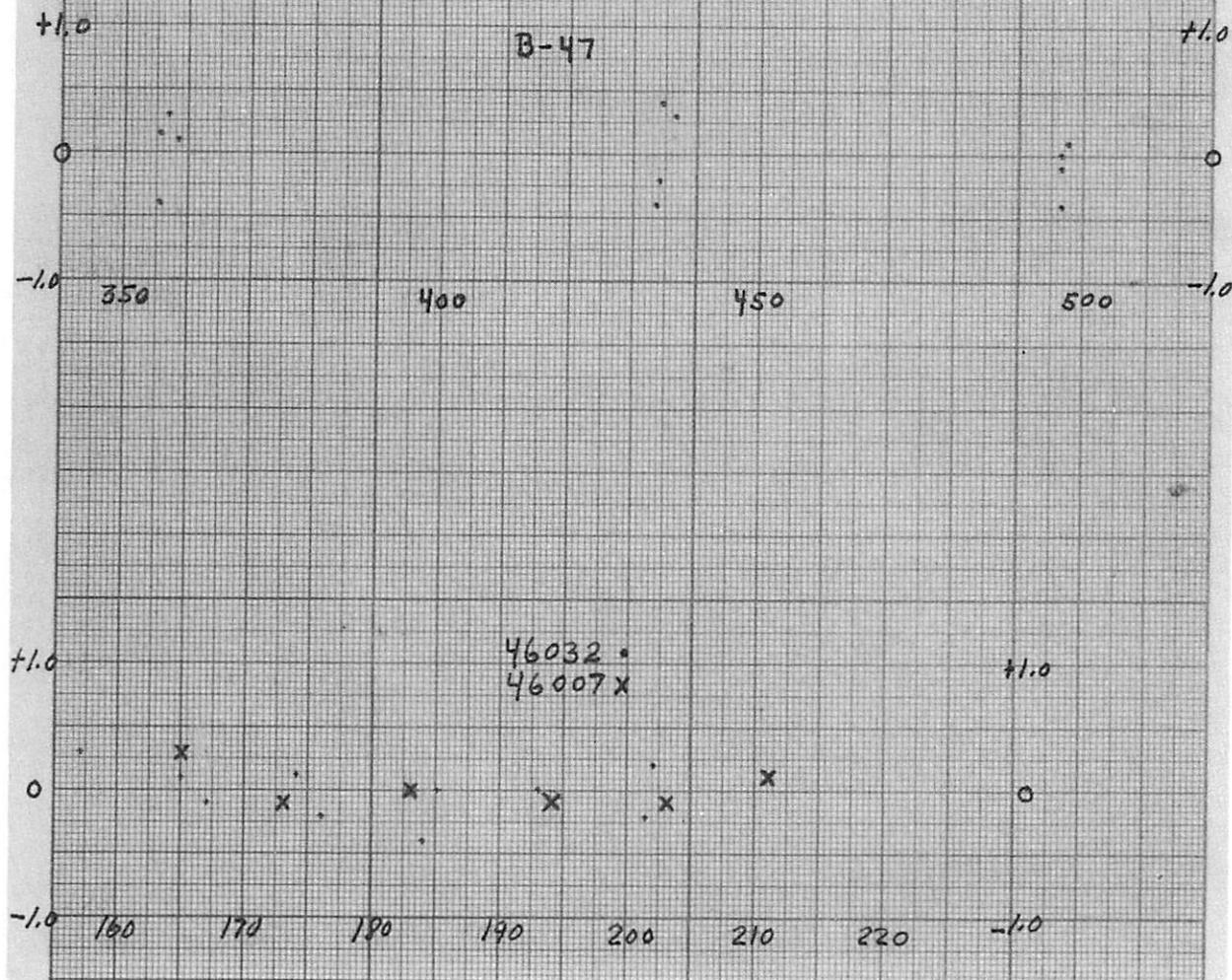
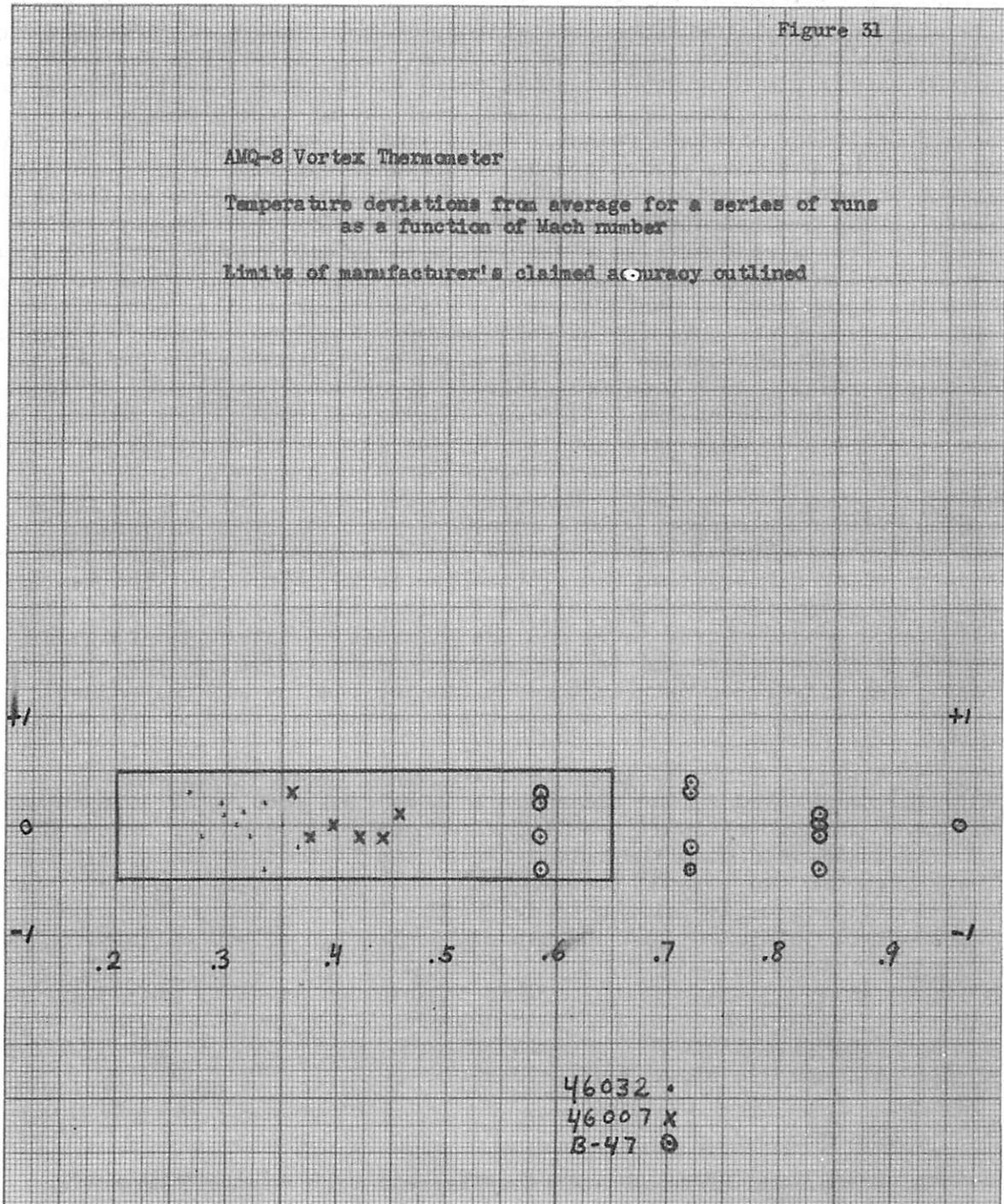


Figure 31



Discussion of results of calibration by airspeed method: Position error is a function of the disturbed pressure field created by the motion of the airplane and is dependent on altitude only to the extent that the small compressibility effect depends on altitude. This dependence has been neglected here. The disturbed pressure field varies with flight altitude or angle of attack and indicated airspeed. Angle of attack in non-accelerated flight is a function of aircraft weight. To determine the effect of angle of attack of B-50's on position error, graphs of airspeed position error versus aircraft weight at several indicated airspeeds were prepared as shown in figure 27. These curves demonstrate no systematic variation of position error with gross weight. Test speeds were at a minimum, normal, and maximum cruising speed and cover the interval between 160 and 210 knots indicated airspeed. Since the cruising speed used on NHRP flights is within these limits, aircraft weight was disregarded for purposes of calibration. Absolute accuracy of the airspeed position error calibration is estimated to be ± 2 knots. At 700 mb. this uncertainty results in a pressure-altitude error uncertainty of ± 58 feet. At 500 mb. the uncertainty is ± 77 feet. During the 1956 flight season, insufficient calibration data were obtained during flights of the B-47 to complete the determination of all of the corrections for that aircraft.

b. Altimeter method. - This method of position error determination makes use of two altimeters, one to measure true atmospheric pressure on a tower, and the other connected to the static-line in the airplane. The two instruments are read simultaneously as the airplane flies by the tower. Altitude difference between tower level and the aircraft is determined trigonometrically by use of a theodolite and is used in the comparison of the two altimeter readings. The difference between tower altimeter reading and the adjusted aircraft altimeter reading is the pressure-altitude position error of the static ports.

As a check of the airspeed position error calibration, one of the NHRP TB-50's was calibrated by the altimeter method. The results of this method were within 20 feet of altitude position errors determined by the airspeed method. As 20 feet is less than the resolution of the altimeters it is felt that the results of the two methods confirm each other and justify the basic assumption of the airspeed calibration method. Figure 28 shows the altimeter method position error points and the corresponding airspeed method calibration curve.

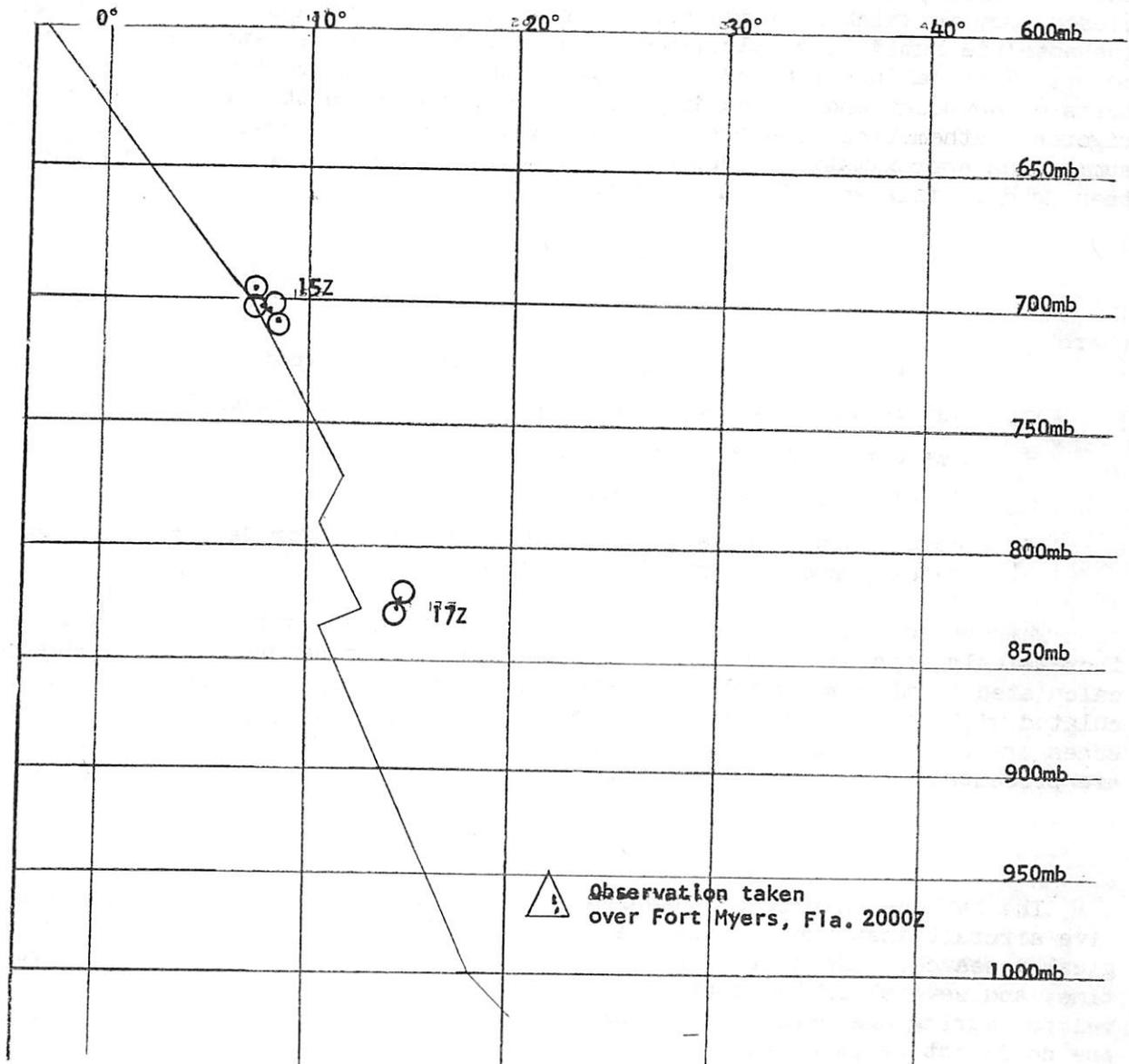
3. True Airspeed Calibration. - This calibration involves only a direct comparison of airspeeds computed by the AN/APN-82 system with true airspeeds calculated from ground speeds. Curves of error versus true airspeed were fitted to the data and are shown in figure 29.

4. Flight Checks of AMQ-8.

a. Comparison of temperatures measured by the vortex thermometers at various airspeeds. - In order to determine any effect of airspeed on the temperature indicated by the vortex thermometers, a series of temperature versus speed runs was performed. The airplanes repeatedly flew a straight-line path over a fixed reference point, maintaining constant altitude at various airspeeds. Vortex temperatures were recorded on punch cards. Temperature deviations from average for a series of runs are plotted against true airspeed in figure 30. These temperature deviations are illustrated as a function of Mach number in figure 31, which also shows the rated limits of accuracy mentioned by the manufacturer. All of these tests were conducted in clear air.

Figure 32

Comparison of Vortex Thermometer and Radiosonde Temperature over Tampa, Florida, at 1500Z on October 29, 1956.



b. Comparison of temperature by vortex thermometer with temperature by radiosonde. - On October 29, 1956, temperatures indicated by vortex thermometer were recorded on one of the TB-50 airplanes while flying in the vicinity of Tampa, Fla. These temperatures were plotted with the sounding taken by the U. S. Weather Bureau at Tampa, and are shown in figure 32. The times of the aircraft observations are shown.

C. CALIBRATIONS FURNISHED BY OTHER AGENCIES

1. NACA Icing Rate Meter. - Calibration curves for measurements made by the NACA icing rate meters were furnished and are available, but are not presented here.

2. Infrared Hygrometer. - The infrared hygrometer was calibrated by the U. S. Weather Bureau, Instrumental Engineering Division. It was calibrated in a closed room in which humidity was controlled. Its readings were compared with the absolute humidities calculated from measurements made with a sling psychrometer. This calibration has been adapted at NHRP to present the calibration in terms of dewpoint and of readings of the meters used in the aircraft. Because rigorous mathematical conversion of absolute humidity to dewpoint is time-consuming, an approximation based on the equation of state for water vapor has been used. This equation has the form

$$T = \frac{e_w}{C_v R_w \rho_w}$$

where

T = temperature of water vapor at saturation = dewpoint,

e_w = saturation vapor pressure over water at temperature T,

R_w = gas constant for water vapor,

ρ_w = density of pure water vapor,

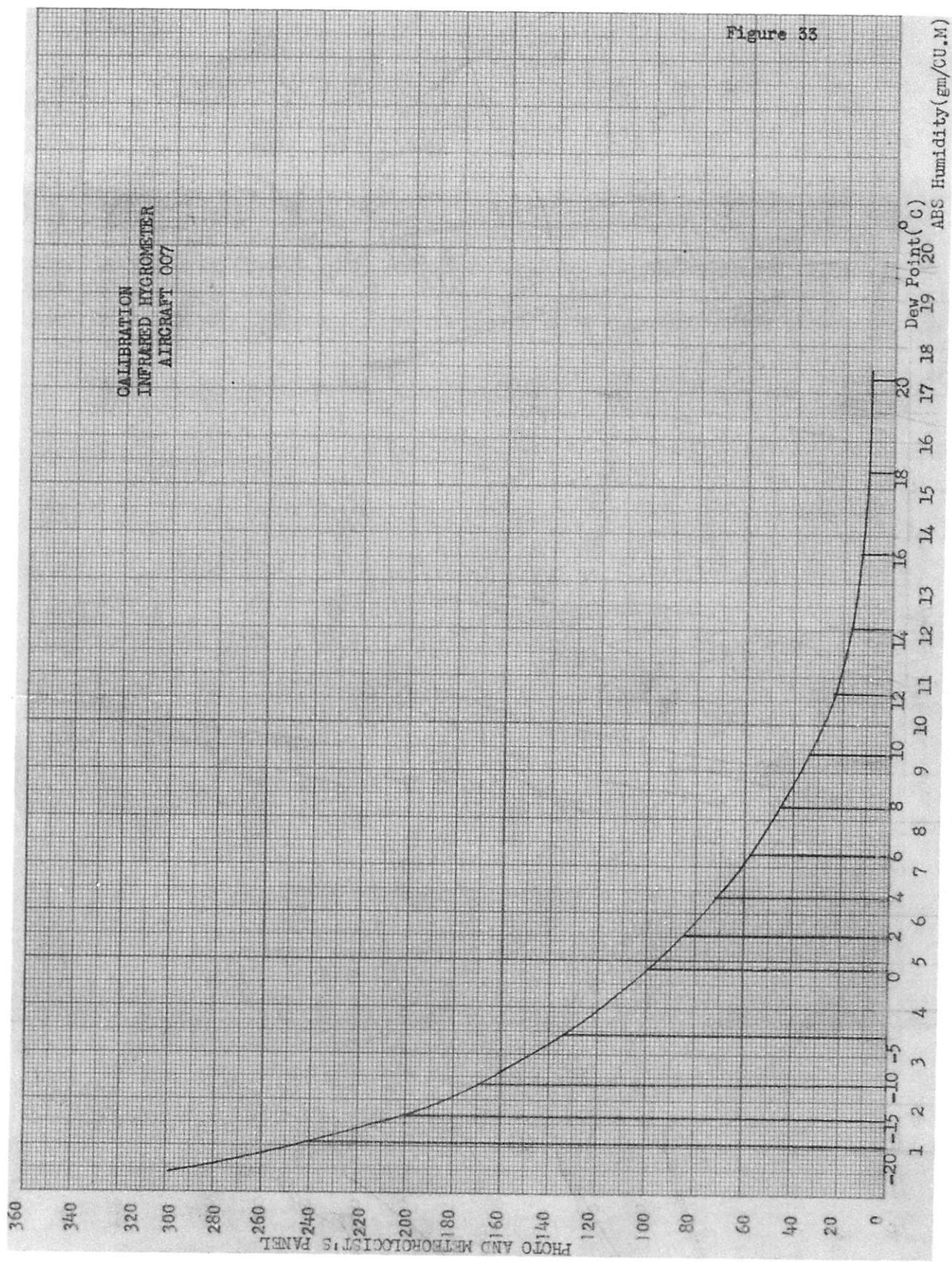
C_v = compressibility factor for water to correct for deviations of water vapor processes from ideal gas laws.

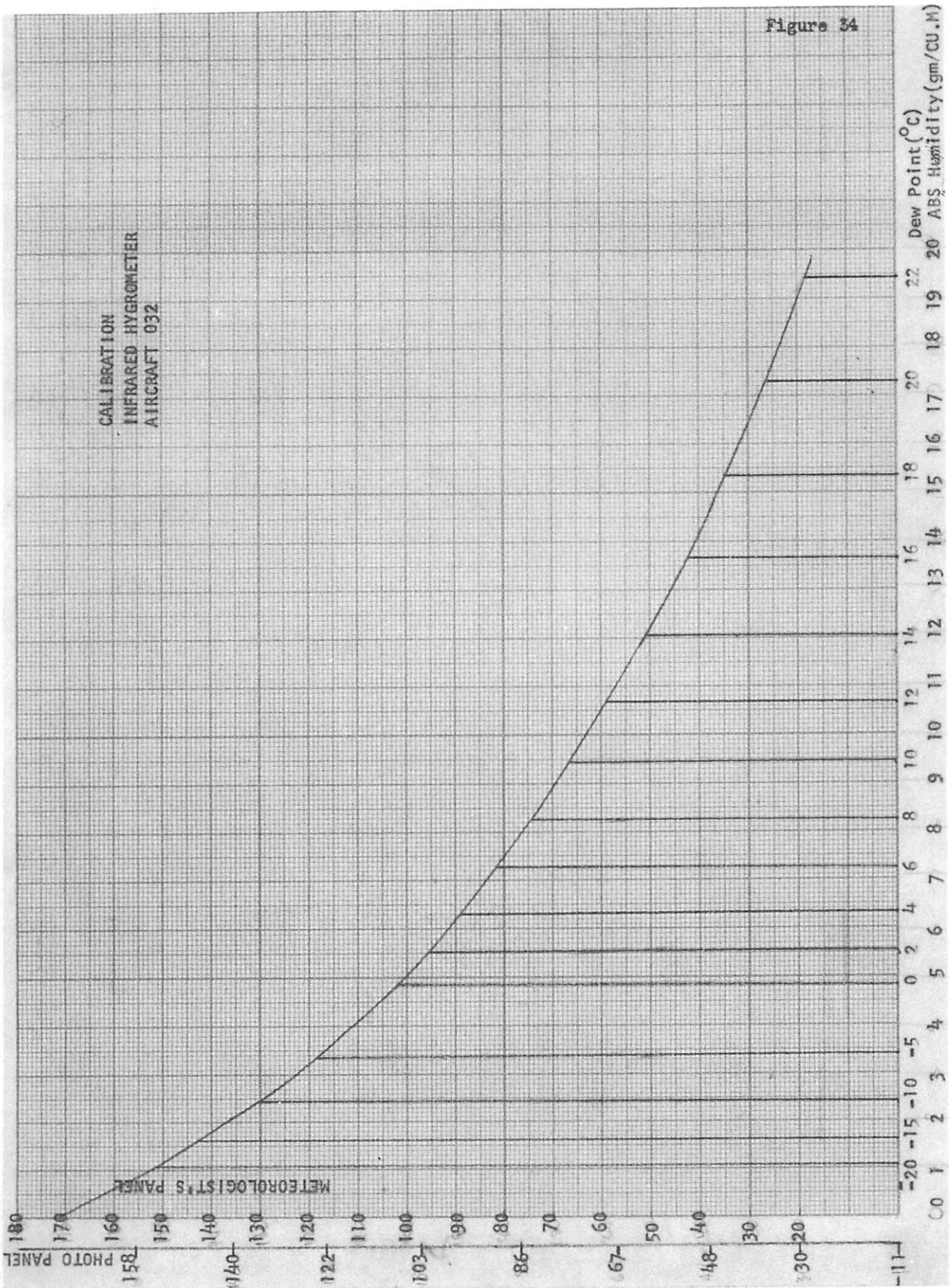
This approximation is very nearly correct for saturated air but becomes increasingly inaccurate with decreasing humidity. At saturation, the dewpoints calculated in this manner do not differ by more than 0.1°C. from dewpoints calculated without approximations. At relative humidity 20 percent, the differences are near -1.0°C. Complete calibration curves for the infrared hygrometers are presented as figures 33 and 34.

III. CONCLUSION

The National Hurricane Research Project aircraft contain the most extensive aircraft instrument systems ever installed for the purpose of meteorological research. The systems were organized and installed in only a few months' time, and several of the instruments and recording systems were completely developed during the period. A rushed instrumentation program as complex as this one could not be expected to be uniformly successful.

The D-Value computers were the most important disappointment. Repeated





flight tests of this equipment demonstrated that the nickel delay line principle was sound, but that the BC-788 radar transmitter-receiver did not possess a great enough signal-to-noise ratio to permit proper operation of the computer. Other methods are now being developed which are expected to permit measurement of D-Values during the 1957 season.

Another important fault was the unreliability of the photo panel cameras. The photo panel recording system which had been intended as a backup to the other recording systems proved to be the least dependable. Part of the difficulty can be explained by the lack of experience of the personnel servicing the cameras.

Various instruments were not completely installed by the time of onset of the 1956 hurricane season and the heavy flight program did not allow completion of all of the installations during the season. The reverse-flow thermometers, the sea surface temperature radiometers, the electric field meters, and parts of the WADC turbulence instrumentation and the cloud physics instrumentation can not be considered as brought into operational use.

The most successful component of the system was the digital recording system. Its combination with the AN/APN-82 equipment proved to be very effective.

The calibrations of the instruments and of the aircraft are not complete, but tests that have been made are encouraging. It is planned to recheck and complete the calibrations prior to the 1957 flight program.

It is expected that the experience acquired during the 1956 season will permit much more complete utilization of the instrumentation during succeeding years. Certain improvements based on this experience are now in progress.

APPENDIX

A. Corrections for Meteorological Data

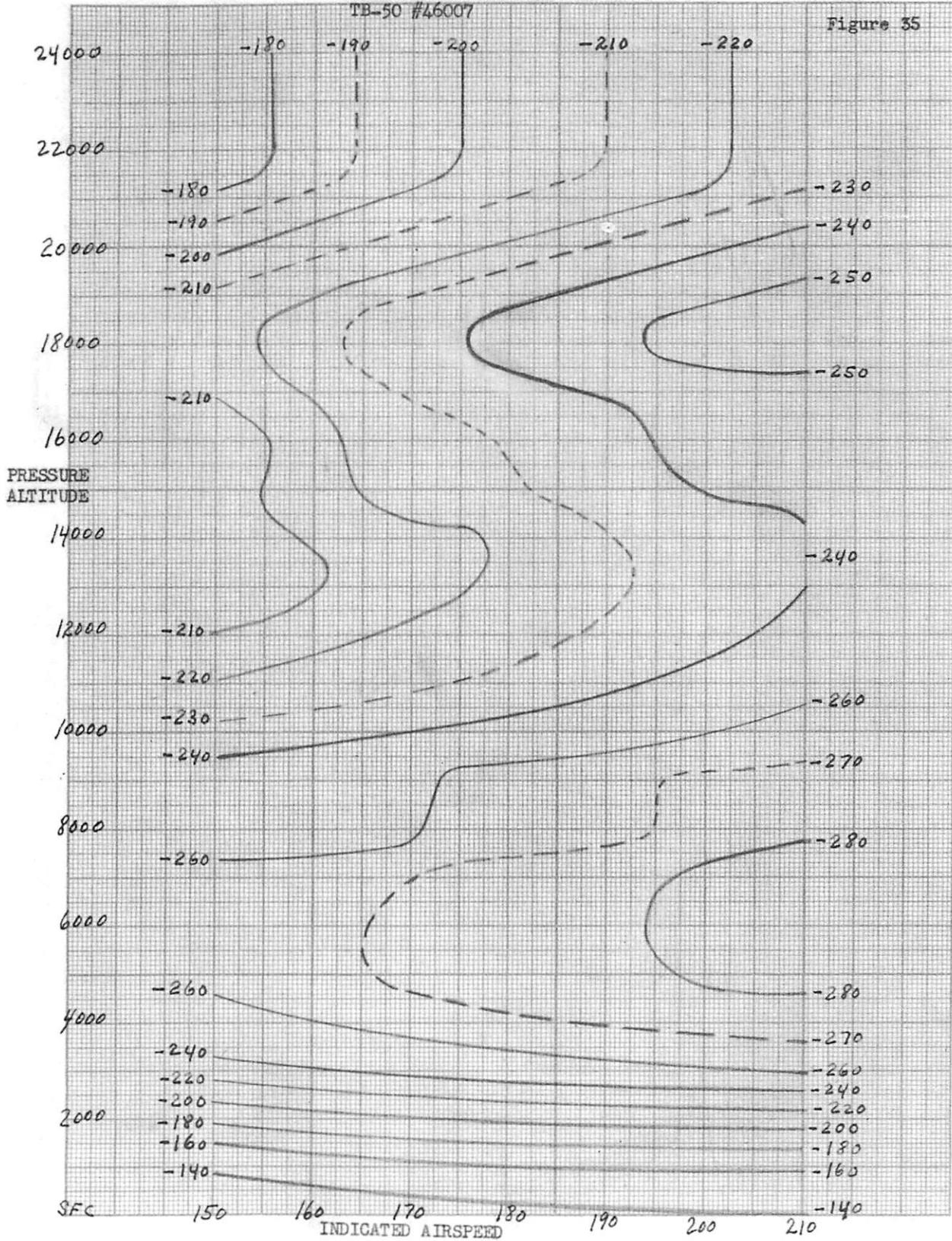
1. Photo panel altimeter, aircraft No. 46007 - figure 35.
2. Bombardier's altimeter, aircraft No. 46007 - figure 36.
3. Photo panel altimeter, aircraft No. 46032 - figure 37.

B. Estimated Accuracies and Dynamic Factors

1. Master timer
Accuracy: ± 0.1 percent
2. Pressure-altitude
 - a. D-Value computer
Accuracy: ± 20 feet after corrections are applied
 - b. Kollsman altimeters
Accuracy: ± 80 feet after corrections are applied
3. Radio altitude: - SCR-718
Accuracy: ± 50 feet
4. Compass headings
Accuracy: to ± 0.2 degrees
5. True airspeed: - A-2 computer
Accuracy: ± 2 knots after corrections are applied
6. Indicated airspeed
 - a. Transducer
Accuracy: ± 1 percent
 - b. Kollsman I.A.S. meter
Accuracy: ± 1 knot after corrections are applied
7. Temperature
 - a. Vortex thermometer
Accuracy: $\pm 0.5^\circ\text{C}$.
Servo response rate: 2° per second
Response time: 10 seconds
Recovery factor: Zero
 - b. Stagnation thermometer
Accuracy: $\pm 0.5^\circ\text{C}$.
Servo response rate: 12° per second
Recovery factor: 0.87 for airspeed in knots
 - c. Reverse-flow thermometer
Accuracy: $\pm 1^\circ\text{C}$.
Recovery factor: 0.537 for No. 46007; 0.624 for No. 46032
8. Humidity: - Infrared hygrometer
Accuracy: $\pm 1.1^\circ\text{C}$. for dewpoint in range from 15°C . to -7°C .,
 $\pm 0.3^\circ\text{C}$. between -18°C . and -7°C .
Response: Full scale in 15 to 20 seconds
9. Sea surface temperature
Accuracy: $\pm 2^\circ\text{C}$.
10. Electric field meter
Accuracy: ± 4 percent

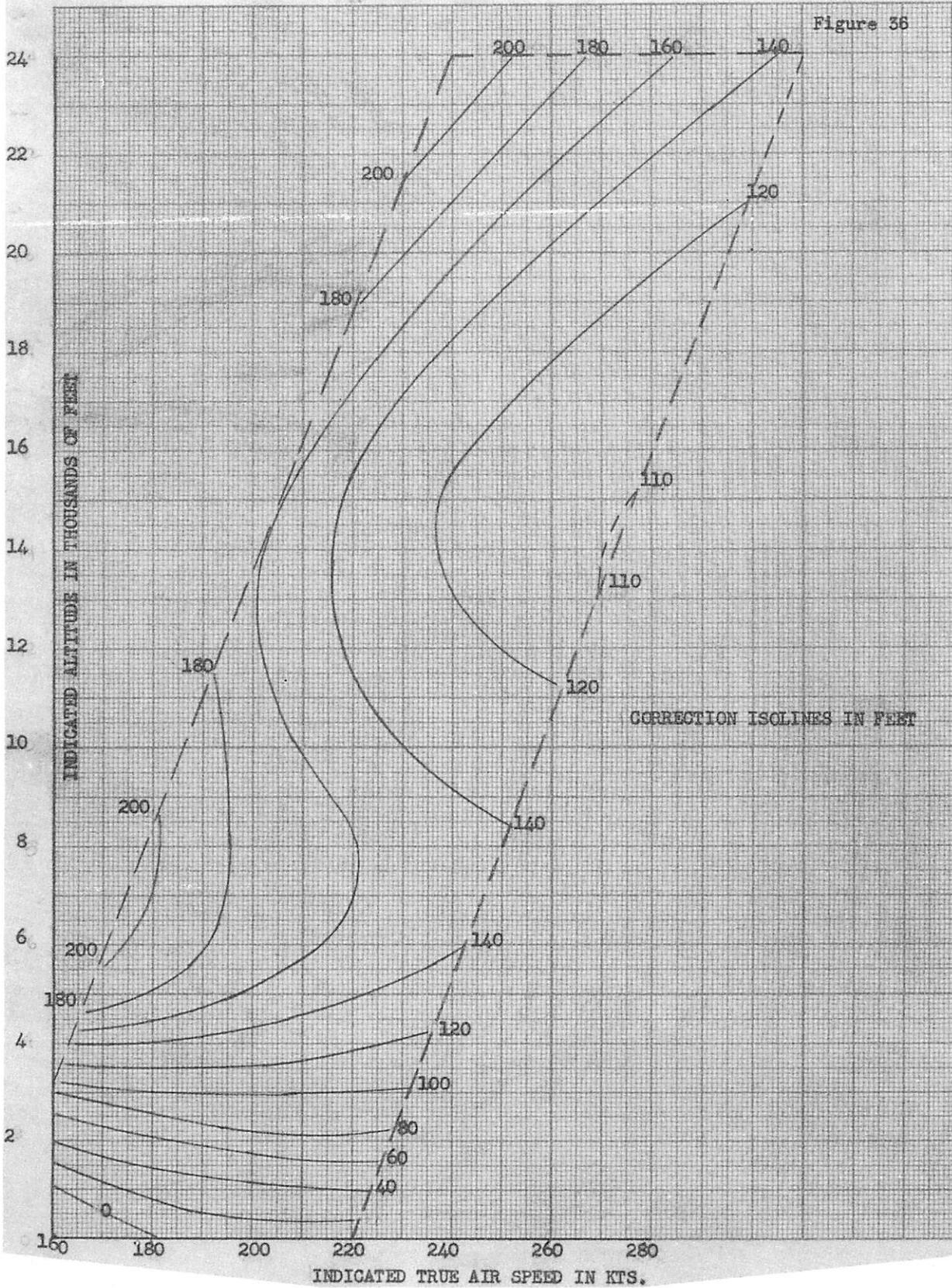
SUM OF CORRECTIONS
 PHOTO-PANEL ALTIMETER #206770
 TB-50 #46007

Figure 35



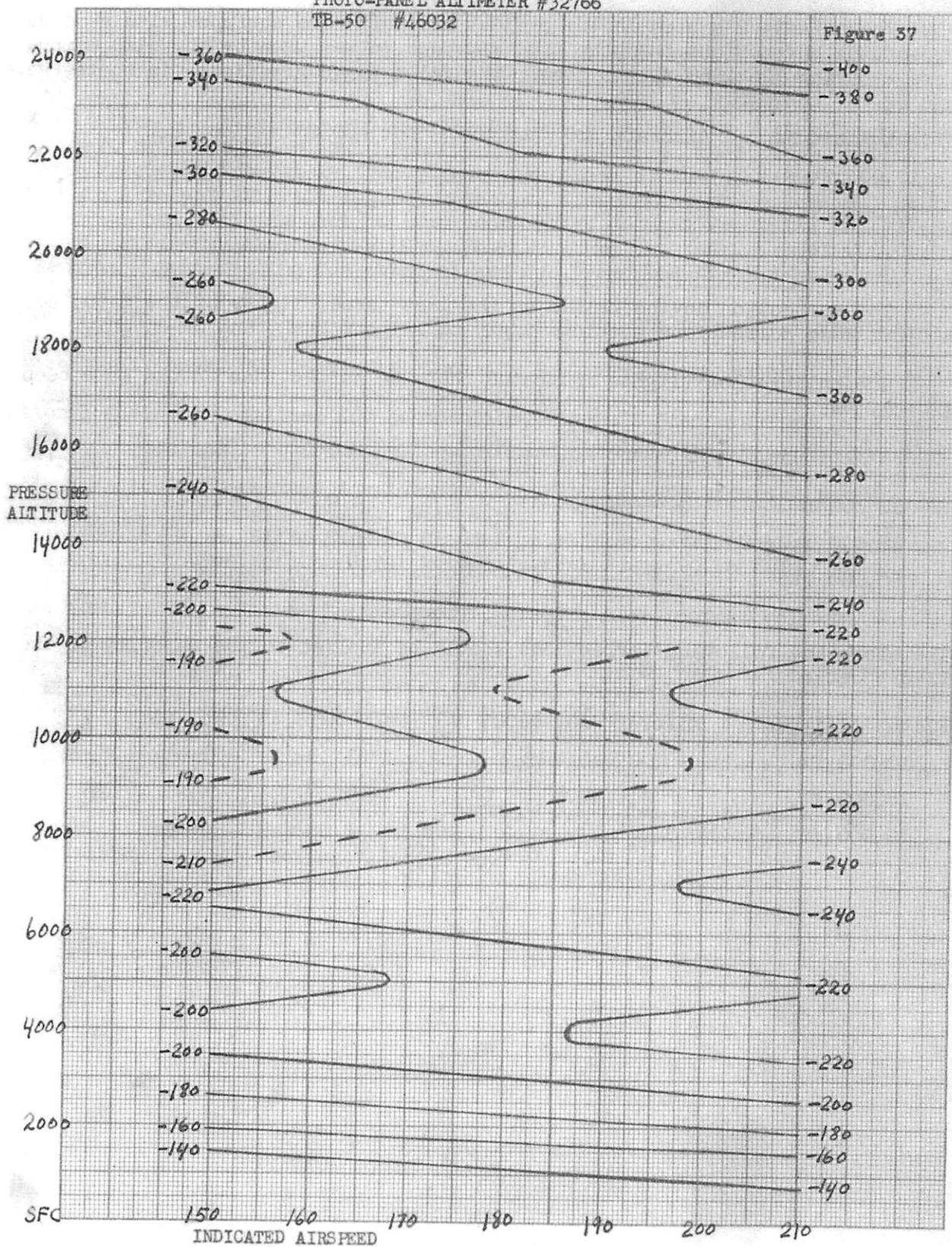
COMPLETE CORRECTION FOR BOMBADIERS ALTIMETER
SERIAL 127-121 IN TB-#46007

Figure 36



SUM OF CORRECTIONS
PHOTO-PANEL ALTIMETER #32766
TB-50 #46032

Figure 37



C. True Airspeed Corrections for AN/APN-82 Systems

The AN/APN-82's used in the project aircraft were equipped with a means of setting corrections into the true airspeed values used by the wind computers. During the 1956 flight season the following corrections, in knots, were set in:

Flight Altitude	Aircraft No. 46007	No. 46032	No. 2115
10,000 ft.	-1	+3	0
18,000 ft.	+1	+3	0
30,000 ft.	-	-	0

The correction device failed on the last three flights of the B-50, No. 46032. Zero corrections settings apply to flights SR-24 and SR-25 only.

The calibration flights indicated that the corrections should have been as follows:

Flight Altitude	Aircraft No. 46007	No. 46032	No. 2115
10,000 ft.	-0.6	+6.0	-
18,000 ft.	+1.4	+6.0	-
30,000 ft.	-	-	+6.0

Therefore the following corrections should be applied to the majority of the flight data:

Flight Altitude	Aircraft No. 46007	No. 46032	No. 2115
10,000 ft.	+0.4	+3	-
18,000 ft.	+0.4	+3	-
30,000 ft.	-	-	+6

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