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LONG PATH, VISIBLE AND INFRARED TRANSMISSOMETER: CALIBRATION AND USE

THESIS

Presented to the Faculty of the School of Engineering of the Air Force Institute of Technology Air University in Partial Fulfillment of the Requirements for the Degree of Master of Science

by

Leo O. Vroombout Graduate Engineering Physics

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Abstract

The Barnes Model 14-WP transmissometer is one of the principle optical path calibration instruments of the Air Force Avionics Laboratory's Targeting Systems Characterization Facility. A simple test based on LOWTRAN IIIB was devised to certify system calibration while installed on an eight kilometer optical path. In addition, an optical path anomaly was investigated. Results are discussed and recommendations for additional calibration tests and new procedures are made.

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LONG PATH, VISIBLE AND INFRARED TRANSMISSOMETER: CALIBRATION AND USE

I. Introduction

Background

During the war in Southeast Asia, it became more obvious than ever before that our forces must have the ability to prevent the enemy from taking advantage of darkness and adverse weather to move troops and supplies. One of the more successful sensors to be developed to satisfy this requirement was the Forward Looking Infrared set (FLIR). Although the FLIR concept had been demonstrated in the mid- 1950's. the electronics technology was not sufficiently developed to permit developing a useful, airborne FLIR until 1965 when the first exploratory development FLIR was tested in Southeast Asia. From then until 1974, over sixty different types of FLIR's were developed and several hundred were produced (Ref 11:5).

Throughout this period, the emphasis was on improving infrared (IR) detectors as well as the associated signal processing electronics and optics. However, by the end of this period, as cost increases began to exceed performance increases, the emphasis shifted toward better understanding of the physics of thermal imaging. Such improved understanding lead to computer modeling of the FLIR and its military appli-

cation. These models are intended to determine the extent to which FLIR performance must imporve, if at all, in order to satisfy future military requirements. For instance, a major question to be answered prior to developing the next generation Air Force FLIR is what is the optimum spectral window for its operation? Does it fall within the 3 to 5 or 8 to 12 micrometer atmospheric windows? The models should answer this question. Unfortunately, there is little confidence in certain parts of the models; two particularly poor areas involve atmospheric propagation under very low visibility conditions and dynamic (search) modeling (Ref 23:2). This thesis will address the atmospheric propagation issue.

Atmospheric Transmission. The importance of atmospheric effects on the IR energy emitted by a target and received by a FLIR is well documented (Refs 1; 11:30-52; 12; 15; 22:10-16; 23: chap 3; 25: chap 6). The most important effects are (1) attenuation of the target energy by molecular absorption and by scattering out of the path, (2) scattering of back-ground energy into the path, (3) the IR radiance of the air mass in the path, and (4) optical turbulence along the path.

The first three effects have been under study both in the laboratory and in the field since the late 1950's. In fact, in 1957, T. L. Altshuler (Ref 4) published a set of curves which may be used with reasonable confidence whenever the total transmission is greater than 20 percent. More recently, the laboratory and field data have been complied and made available in the Air Force Geophysics Laboratory

computer program LOWTRAN (Refs 13; 17; 18; 19). It is generally agreed that the most recent version of LOWTRAN, LOWTRAN IIIB (Ref 19), provides quite accurate transmission values when the total path transmission is greater than 10 per cent and scattering losses are low (Ref 23:1-13); however, when scattering losses are high, LOWTRAN departs from measured data by as much as a factor of three (Ref 16).

The fourth effect, optical turbulence, is the subject of current research (Refs 1; 2:31-35). As a result, only quasi-empirical mathematical models are available for engineering estimates of the degradation due to optical turbulence; these estimates do agree favorably with the limited experimental data that exist at this time (Ref 2:4).

This thesis will be concerned primarily with the first effect, attenuation by absorption and scattering. An overview of atmospheric transmission theory is provided in chapter II. Appendix A contains a computer listing of the modified LOWTRAN program developed for this thesis.

Atmospherics Effects Measurement Program. Because of the need to validate electro-optical sensor mathematical models and because of the lack of reliable atmospheric transmission data (Ref 11:31), particularly under low transmission/ high scattering conditions, the Air Force Avionics Laboratory (AFAL) has established an Atmospheric Effects Measurement Program within its Targeting Systems Characterization Facility. This facility consists of electro-optical imaging sensors, including FLIR's, and test equipment, targets and mete-

orological instrumentation. The intent is to provide a fully characterized, eight kilometer, optical path between the sensors and the targets. To accomplish this, standard meteorological instruments as well as aerosol particle counting and sizing instruments are located at the zero, four and eight kilometer positions along the optical path. In addition, a Barnes Model 14-WP transmissometer (0.5 to 14 micrometers) is located so as to measure the spectral transmission along the eight kilometer path. The data from the transmissometer and the other instrumentation will provide the optical path calibration and will also be available to validate or to provide corrections to LOWTRAN. In the latter case, the transmissometer is the most important instrument; its calibration is one of the first tasks in the Atmospheric Effects Program and is the primary concern of this thesis. A summary of transmissometer theory is contained in chapter III.

<u>Transmissometer Calibration</u>. An IR transmissometer consists of a standard source of thermal radiation and a projector for that energy (somewhat like a searchlight) and a receiver that collects the energy after it has been attenuated by the atmosphere. The receiver electronics then convert the energy into a recordable output.

No standard procedure exists for calibrating a transmissometer; however, those procedures that do exist have several features in common. The receiver is first set up in the laboratory looking into its own source or at another blackbody reference source. The electronics are then adjusted so

that a known relationship exists between this measurement and, based upon geometric arguments, that which would be expected on the test range. Then the transmissometer is installed and, if possible, some simple test is devised to verify the calibration *in situ*. This test usually consists of comparing the measured data to LOWTRAN predictions during periods of high transmission with low scattering (Refs 7:7).

In addition to transmissometer theory, chapter III also contains a description of the Barnes Model 14-WP transmissometer and of its installation in the AFAL Targeting Systems Characterization Facility. Chapter IV contains a description of the experiments performed with the transmissometer and the results. Chapter V contains a summary of the work under this thesis and recommendations for additional calibration testing. Appendix B is a draft calibration handbook for the transmissometer.

Objectives

The objectives of the work described on this thesis were as follows:

a. develop an understanding of the principles of operation of the transmissometer,

b. devise a simple test to verify the transmissometer calibration while installed on the eight kilometer range,

c. identify those areas which require additional calibration testing,

d. conduct the initial transmission measurements

prior to the transmissometer's being interfaced with the facility's automatic data processing equipment.

The last objective was not fulfilled partly because of equipment malfunction and partly because of visibilities that were too low to permit alignment and calibration.

II. Atmospheric Effects

The atmosphere is important to all living creatures on this world not only because of the gases that are breathed and the rain and heat retention that are provided but also because of the protection from harmful solar radiation. None of these things could be provided if the atmosphere did not absorb electromagnetic radiation. As desirable as this feature is, it is undesirable to people or sensors that need to see through the atmosphere for long distances. Consequently, it is necessary to identify and quantify the atmospheric effects on electromagnetic radiation so that they at least might be corrected for. This chapter provides an overview of atmospheric attenuation mechanisms, a brief description of the most commonly accepted atmospheric transmission model and a brief description of a modification that was accomplished on that model for this thesis. Samples of the output of the model are included in the fourth chapter.

Atmospheric Attenuation Mechanisms

As it propagates through the atmosphere, visible and infrared radiation are selectively absorbed by several atmospheric gases and scattered away from the direction of propagation by aerosol particles suspended in the atmosphere. Excellent summaries of these effects have been written by Hudson (Ref 9: chap. 4). Lloyd (Ref 11: chap. 2), and Wolfe (Ref 25: chap. 6). Middleton (Ref 15) has written an excellent reference text on seeing through the atmosphere and McCartney (Ref 12) has

discussed the scattering processes in great detail. The following discussion is drawn primarily from these sources.

The general process of attenuation of radiation as it passes through the atmosphere is called extinction. For monochromatic radiation, the transmittance along a path may be expressed by the Lambert-Beer law

$$T = \exp(-\sigma R) \tag{1}$$

where T is the transmittance, σ is the extinction coefficient and R is the length of the path. The extinction coefficient may be further separated into

$$\sigma = a + \gamma$$
 (2)

where a is the absorption coefficient and γ is the scattering coefficient; botheof these coefficients vary with wavelength. Absorption is primarily a function of molecular excitation and affects the infrared more than the visible spectral region. On the other hand, scattering is a function of particle size and, under most weather conditions, can cause greater attenuation in the visible than in the IR.

Visible and Near-IR Spectral Region. Extinction in this region is primarily caused by scattering by gas molecules (Rayleigh scattering) and haze (Mie scattering); however, water vapor molecular absorption does become important in the near-IR region. Energy scattered out of the path and then back again could also have an effect on transmission measurements. Such an effect should be very small if the

transmissometer receiver has a very small field of view. Stewart and Curcio (Ref 20:804) derived an equation for this effect

$$T_{e} = T + 0.5(1-T)(1-e^{-\theta})$$
 (3)

where T_{θ} is the transmittance measured by an instrument having **hafieg** of view of θ radians and T is the transmittance that would have been measured in the absence of scattered light. For fields of view smaller than one degree, T_{θ} and T are the same except under conditions of very low transmission; i.e., less than three per cent.

<u>Far-IR Spectral Region</u>. Extinction in this region is primarily caused by molecular absorption. The most important absorbers are water vapor and carbon dioxide. Water vapor has both a discrete and a continuum absorption in this region. The latter is not well understood but has been measured. Scattering becomes the dominant extinction mechanism only for low visibility or for low temperature, low absolute humidity conditions.

<u>Middle-IR Spectral Region</u>. Extinction is this region is caused by both molecular absorption and scattering; however, there are discrete spectral regions (around 2.2 and 3.8 micrometers) in which transmission through haze is better than in the visible and transmission through water vapor is better than in the far-IR (Ref 2:6).

LOWTRAN IIIB

Because of the widely varying value of the extinction coefficient as a function of wavelength and even more so as a

function of atmospheric conditions (Pressure, temperature and absolute humidity), many attempts have been made to develop useable models for estimating atmospheric transmittance. Altshuler wrote one of the best early models (Ref 4); however, it was too cumbersome because of the use of scaled graphs. McClatchey et al, of the Air Force Geophysics Laboratory (formerly the Air Force Cambridge Research Laboratory), followed Altshuler's approach, added a lot of curve fitted empirical data (both laboratory and field measurements) and developed a very flexible computer model, which in its latest version, is called LOWTRAN IIIB (Ref 19). The code permits calculating atmospheric transmittance in the spectral region from 0.25 to 28.5 micrometers along arbitrary, slant paths. Any one of six standard atmospheric models may be used or meteorological or radiosonde data may be inserted. Five different aerosol models are also available; however, only the maritime model is said to compare favorably with measurements over the European continent during conditions of low visibility (Ref 16). In the absence of aerosol scattering, LOWTRANS's accuracy is stated to be within a few per cent (Ref 7).

LOWTRAN predicts atmospheric transmission by calculating the attenuation for each of the following contributors:

a. water vapor line absorption (350-14500cm⁻¹)

b. uniformly mixed gases (CO_2 , N_2O , CH_4 , CO, N_2 , and O_2) line absorption (500-8060 and 12970-13190 cm⁻¹) c. ozone line absorption (575-3270 cm⁻¹)

d. nitrogen continuum (2080-2740 cm⁻¹)

 cm^{-1})

e. water vapor continuum (670-1400 cm⁻¹)

f. molecular scattering $(2740-40000 \text{ cm}^{-1})$

g. aerosol scattering and absorption (350-40000

h. ozone absorption $(13000-23400 \text{ cm}^{-1})$ The total transmittance for a 20 cm⁻¹ frequency interval is then obtained by multiplying the individual transmittances obtained from the above attenuations. This procedure is repeated throughout the spectral region of interest in increments of 5 cm⁻¹ or greater, as specified by the user. This approach has been shown to be valid for transmissions greater than about 30 per cent (Ref 23:24) and is probably valid down to about 10 per cent (Ref 23:1-14) provided that aerosol scattering is not the primary loss mechanism. Very little experimental data exists with which to correct or to validate LOWTRAN under low transmission/high scattering conditions.

Modified LOWTRAN IIIB

A substantial portion of the LOWTRAN IIIB program is concerned with computing transmission along slant paths. Since the optical path for this thesis is practically horizontal, these cards were removed. In order to increase the program's flexibility, several DO loops were added to permit iterating the temperature, dew point and visibility and plotting transmission as a function of the iterated variable or as a function of wavelength. A source listing is contained in appendix A.

III. The Transmissometer

As mentioned in the first chapter, a transmissometer consists of a standard radiation source, a projector for that radiation and a receiver that collects the radiation after it has propagated through the atmosphere. This chapter provides a general description of an IR transmissometer, a brief description of the theory of its operation and a specific description of the transmissometer used for the work reported in this thesis, the Barnes Model 14-WP, and of its installation and calibration in the AFAL Targeting Systems Characterization Facility.

General Description

An IR transmissometer uses a high temperature black body as the source of its radiation. The source is usually maintained at a constant temperature by constant current electronics and its own thermal inertia. The radiation from the source floods an aperture which is located at the focal plane af the projector. In order to provide background discrimination, the energy is usually chopped at 1000Hz or more just in front of the aperture.

The projector is best compared to a searchlight, although, in essence, it is a collimator. The energy entering the aperture is collected by an off-axis paraboloid or by an on-axis paraboloid in a Newtonian configuration. The energy is then projected into the atmosphere in a highly collimated beam; the smaller the aperture, the greater the collimation.

For a true point source, the beam would be perfectly collimated.

After propagation through the atmosphere over a specified range, the beam is incident upon the receiver. The receiver optics, usually Cassegrainean, then focus the radiation upon a detector which is sensitive to IR energy in the wavelength region of interest. The wavelength region is normally defined by inserting a spectral filter in the optical path in front of the detector. The detector converts the IR energy into an electrical signal which is amplified and processed and then presented to the experimenter either as an irradiance value or as a transmission value. In the latter case, the transmission is defined to be the ratio of the IR energy actually collected to that IR energy which would have been collected if there were no intervening atmosphere. The next section details the procedure for calculating the energy that would have been collected in the absence of an atmosphere.

Theory

One of the most comprehensive articles on beam projectors was written by Frank Benford in 1945 (Ref 5). Unfortunately, this article was only concerned with aspheric optics (the transmissometer used for this work had a spherical mirror). Klein (Ref 10:136-138) provides a reasonably detailed description of a searchlight using a spherical mirror as does Hudson (Ref 9:227-228). The following discussion is drawn from these sources.

Figure 1 shows a single mirror collimator/searchlight (source size and angles are exaggerated for clarity). The



Fig. 1. Searchlight Ray Trace

limiting rays are depicted for bundles originating at the center and at one edge of the source. The angular beamwidth is equal to the ratio of the size of the source to the focal length of the mirror. The irradiance in the beam is independent of the distance from the mirror at all points in the central cone to the right of the crossover point. This occurs when the field point is close enough that the source aperture is the aperture stop. Beyond the crossover point, the irradiance in the beam falls off inversely with the square of the distance from the mirror provided that the field point is still in the central cone. In this case, the mirror is the aperture stop and increasing the source aperture size does not change the irradiance at the field point, only the beam diameter. The equations governing the irradiance at a field point in the central cone are, from Klein (Ref 10:137)

 $E_{near} = L \pi r_s^2 / f^2$, $D < R_1 f / r_s$ (4)

$$E_{far} = L_{\pi}R_1^2 / D^2$$
, $D \ge R_1 f / r_s$ (5)

where

E =	irradiance (before or after crossover)
L =	radiance of the source
r _s =	radius of the source aperture
f =	focal length of the mirror
$R_{1} =$	radius of the mirror
D =	distance to the field point

Note that the distance from the mirror to the crossover point is $R_1 f/r_s$ and that the beam angular width is $2R_s/f$. All of these equations are small angle approximations; this is justifiable since the angles involved typically range from a fraction to a few milliradians.

In practice, a source aperture should be selected such that the central cone diameter at the field point is large enough to compensate for beam wander induced by atmospheric turbulence/scintillation. Also, a very much smaller aperture, R_{cal} , should be selected for calibrating the receiver at zero range. This assures that the receiver electronics are not saturated as well as that the receiver is precisely aligned with the beam projector's optical axis. Then, usi g equations (4) and (5), the ratio of the calibration irradiance to the irradiance at the field point in the absence of the atmosphere is

cal factor = $(R_{cal}D/R_lf)^2$ (6)

Barnes Model 14-WP Transmissometer

Transmitter Assembly. The beam projector of the trans-

missometer used for this thesis consists of a Newtonian telescope, a Barnes 1000° C black body source and a tungsten foil 2820° K color temperature visible light source. Figure 2 is a layout drawing of these components. The radiation from the two sources is combined by a germanium beam splitter and is chopped by a gold plated mechanical chopper (1180Hz) prior to illuminating the aperture plate. The aperture plate is located at the focus of the telescope mirror and contains eight apertures ranging in size from 0.0048 inches in diameter (CAL) to 0.2560 inches in diameter. The telescope mirror has a focal length of 49.5 inches. Its diameter is 16.5 inches, but, allowing for obscuration, the effective diameter is 14.95 inches.



Fig. 2. Transmitter Assembly Layout

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Receiver Assembly. The receiver assembly consists of a Cassegrainean telescope, a continuously variable filter (CVF) wheel, a detector and signal processing electronics. Figure 3 is a layout drawing of those components in the receiver head. Three different receiver assemblies are used to cover the spectral region from 0.5 to 14 micrometers; a silicon detector is used for the spectral region from 0.5 to 1.2 micrometers, an indium antimonide detector for 1.5 to 5.65 micrometers and a mercury cadmium telluride detector for 7.6 to 14.3 micrometers. The field of view of the receiver is 5 mrad for the visible receiver and 2.5 mrad for the IR receivers. The electrical signal from each receiver head is carried by cable to a separate electronics unit. Each electronics unit contains signal amplifiers, a narrow band filter assembly to



Fig. 3. Receiver Optical Layout

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extract only the 1180Hz signal coming from the telescope, a phase lock loop to synchronize the receiver electronics with the telescope chopper, a digital meter and an analog meter to display the transmission reading, the filter wheel drive control and a binary coded digital output to provide transmission and filter wheel position data for computer input. During very low visibility conditions, synchronization may be acheived by telephone modem or by radio transmission and input of the synch signal generated by the telescope chopper.

Installation

The AFAL Targeting Systems Characterization Facility consists of laboratory rooms on the eleventh and twelfth floors of building 620 and a test area, the Trebein site, located five miles east of building 620. The transmitter assembly is installed in a building on the roof (fourteenth floor) of building 620. The receiver assemblies are located in a similar building at the Trebein site. The optical path is 7.944 kilometers long with an average elevation of 318 meters. Meteorological instrumentation is installed at building 620, at the Trebein site and on a tower located at the mid point of the optical path. During the course of the experiment, it was discovered that the weather tower interfered with the optical line of sight between the transmitter and receiver assemblies, and an additional objective of this thesis became to determine the effect of the weather tower on the beam. Calibration

The transmissometer manufacturer provided the calibra-

tion data which is found herein in appendix B. Because of time constraints, it was necessary to accept this data and to install the transmissometer for test. Using the manufacturer's data and equations (4), (5) and (6), it is possible to determine the telescope's beam divergence, the distance to crossover, the size of the central cone at the Trebein site and the calibration factor. These are listed in Table I.

Table I

Source Aperture Diameter (inch)	Divergence (mrad)	Crossover Distance (km)	Central Cone Diameter (m)
0.0048(CAL)	0.097	4.32	0.35
.0081	.164	2.56	0.88
.0141	.285	1.47	1.85
.0256	.517	0.810	3.69
.0444	0.897	.467	6.71
.0810	1.636	.256	12.6
0.1410	2.848	0.147	22.2

Transmissometer Beam Calculation Results

The manufacturer sent an engineer to Wright-Patterson to accomplish the initial calibration prior to installation. The calibration procedure detailed in appendix B was used with the calibration factor of 3.78 (value for 8km) for the peak response filter wheel position. All responses at other filter wheel positions were then determined and filter factors were calculated to normalize all readings to the peak response. The value of this technique is that no absolute

radiometric calibration is required. The limitations are the source output stability and optical transmission changes owing to dust deposits. As a result, periodic recalibration is required. Because of the difficulty of bringing the receiver assemblies to the transmitter assembly, an additional test is required to determine when recalibration is required. Developing this test is the principle objective of this thesis. It is discussed in the next chapter.

IV. The Experiment

As stated in chapter I, equipment malfunctions and uncooperative weather prevented satisfying the objective of conducting the initial transmission measurements as part of the Targeting Systems Characterization Facility program. Consequently, only the weather tower effects and the *in situ* calibration verification procedure/test were accomplished for this thesis. The work and the results are described in this chapter. <u>Note</u>: The transmissometer manufacturer refers to the InSB receiver as the near-Ir receiver; this erroneous labelling is also used in this thesis in order to avoid confusion.

Weather Tower Effects

<u>Results</u>. Initial alignment of the transmitter assembly could not be accomplished until 4 August 1977. Alignment was accomplished by removing the IR source and beam splitter (see figure 1) and looking through a microscope at the image in the plane of the source aperture. No alignment fixture was available; as a result, on-axis alignment was determined by lack of parallax and coma. The azimuth and elevation settings were then adjusted until the appropriate window of the Trebein building was in the center of the field of view; the receivers were located behind the second window from the north corner of the building; the transmitter was located behind the farthest south window of the small building on the top of the building 620 tower (see figure 5). Since electrical

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Fig. 4. Eight Kilometer Test Range.

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power could not be applied to the transmitter assembly at that time, no tests were conducted until 11 and 12 August. Only the visible receiver could be used and it could not maintain phase lock with the incoming beam. After several days of troubleshooting, it became possible to conduct the following test on 18 and 19 August 1977.

The transmitter assembly was visually aligned with the appropriate window of the building at the Trebein site, and the receiver was then aligned by manually adjusting its lineof-sight until a maximum transmission reading was obtained. Then, the size of the transmitter's source aperture was varied. For each position of the aperture wheel, the transmission reading was recorded; since the readings were fluctuating rapidly, maximum and minimum values were estimated visually. Only the 0.68µm position of the receiver filter wheel was used during this test. Next, the receiver was placed on a tripod in front of the next window (2) to the south, the transmitter assembly was aligned to that window and the experiment was repeated. A third set of measurements were also made for the last window to the south. The same sets of measurements were repeated the next day. The mean values of the data are depicted on figure 6 where the numbers 1, 2, and 3 refer to the receiver being located behind its normal window, the next one to the south and the last one to the south, respectively. The transmission readings were better on the first day because the visibility was about 20 miles on the first day and only 15 miles on the second day. Image boil (scintillation) hampered



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the visual alignment and was greater on the first day than on the second day.

The higher transmission readings as the receiver was moved farther south were quire disturbing because the weather tower obstructed the line-of-sight to the normal window (1) only! Consequently, it was decided to repeat the experiments at night when atmospheric optical turbulence would be less and a more precise alignment could be assured. The experiment was repeated the night of 24 August 1977; this time a fourth test position was included, the stairs outside the south side of the building. The data are depicted in figure 7 and listed in table II. A flashlight located at the receiver was used to assure precise alignment of the transmitter assembly. This time the lowest transmission readings are those for the farthest south window (3) and the stairs (4) while the highest readings are still for the southern window (2) adjacent to the normal window (1). As a final check, these measurements were repeated the night of 22 September 1977. Since the visible receiver was not functioning this time, the near IR receiver was used; the filter wheel was stationary at 2.19µm. These data are also included in table II; this time the northern window (5) adjacent to the normal window (1) was included. The measurements at the adjacent southern window (2) are still higher than for the other windows.

Additional information noted during these two tests: 1. As would be expected, based on the field of view plots in the manufacturer's calibration data, the transmission reading

Sou	rce Ap	erture	Visit	le	Trans	missic	on Re	ading	3 24	Au	g 77			
Dia	meter	(inch)	Pos	i'n	1	Pos'n	2	Pos	'n 3	1	Pos	'n	4	
	0.14	05	51.	5±5	. 4**	61.9±4	1.5**	45.5	5±3.	5	43.	5 ± 2	2.8	
	.08	10	50.	0 ± 5	.9	61.5±4	1.9	43.7	7±2.	6	43.	8±2	2.7	
	.04	44	50.	7 ± 4	.1	61.7±4	1.6	42.9)±2.	5	42.	7 ± '	1.9	
	. 02	56	45.	5 ± 4	. 8	54.0±5	5.0	38.5	5±2.	8	36.	4 ± 3	3.4	
	.01	41	33.	8±6	. 8	39.2±2	2.0	29.3	3±2.	5	28.	2 ± 7	1.7	
	0.00	81	29.	2 ± 2	. 2	31.7±2	2.0	22.	±1.	8	17.	0 ± 3	3.0	
			Nea	ir I	R Tra	ansmiss	sion	Read	ing	22	Sep	77		
	0.14	05	19.	8±2	. 4	37.2±4	1.8**			19.	1±3.	3 1	>	
	.08	10	19.	3±1	. 8	36.2±4	1.1			19.	5±2.	5	0	
	.04	44	19.	1 ± 1	. 8	35.3±3	3.1			18.	7±2.	3	S	
	.02	56	14.	6 ± 2	.0	31.4±4	1.0			14.	9±2.	3		N
	0.01	41	9.	0 ± 1	.4	23.0±2	2.6			8.	7±2.	0		5
**	Scinti	llation	was	hig	h dui	ring th	nese	measu	irem	ent	s.			

Table II. Weather Tower Effect Transmission Measurements

is extremely sensitive to receiver misalignment. According to that data, over 35 per cent is lost in transmission reading by angular displacements as small as ±1 mrad. Consequently, any flexing in the floor support of the receiver would cause the transmission reading to change when the person accomplishing the receiver alignment moved away from the receiver. This applies to positions 3 and 4.

2. The peak sensitivity position is not necessaryily in the center of the circle superimposed in the optical viewfinder image.

3. Changing the near IR electronics drawer position can change the transmission reading by as much as 10 to 15 per cent.
4. Turning the visible light source off reduced the near IR transmission reading from over 40 per cent down to 10 per cent.
5. If the receiver is at one window and the transmitter assembly is aligned with the adjacent window, the transmission readings are substantially lower than would be predicted for the larger source apertures and vary substantially less as a function of source aperture size. Representative data are shown in table III including an indication as to whether or not the central spot size should overlap the adjacent window.
6. Scintillation increases the spread in the data even for the largest aperture.

Source Aperture	Transmission	Spot Size	
Diameter (inch)	Reading	Overlap ?	
0.1405	12.0	yes	
.0810	12.2	yes	
.0444	10.7	yes	
.0256	9.1	marginal	
.0141	8.6	no	
0.0081	8.6	no	

Table III. Adjacent Window Measurements

NOTE: The readings increased to 19.0 when the transmitter assembly was aligned to this window.

Discussion. The results of the weather tower tests do not demonstrate conclusively that the tower does or does not have an effect on transmission measurements made at windows one or five. However, the data do permit one general conclusion to be drawn; that the beam profile is not as predicted from theory (see Table I) but has a smaller central cone. The

justification for this conclusion is contained in the following paragraphs.

Consider the slopes of the data plotted in figure 5. Variable alignment would explain the crossover on the 19 August data while different amounts of scintillation would account for the difference in slopes with the lower scintillation yielding the shallower slope on 20 August. The latter point is confirmed by the fact that the spread between the maximum and minimum readings was also reduced for less scintillation. Since using a flashlight at night helped eliminate the possibility of misalignment, the remainder of this discussion will be concerned only with the 24 August and 22 September data (figure 6 and table II).

At night, scintillation was quite a bit less than during the day and precise alignment of the transmitter assembly was assured by using a flashlight located at the receiver at the Trebein site. Although the slopes are even flatter, they still exist; the first aperture showing marked fall-off is the 0.256 aperture. Also, the difference between maximum and minimum readings is as great during the maximum scintillation period at night as during the day even though the scintillation appeared to be less visually; i.e., although the image of the flashlight sometimes moved out of the .0081 in. aperture at night, during the day the whole scene "crawled", and the image of the window sometimes moved most of the way out of the .0256 in. aperture. Since the diameter of the uniformly irradiated central cone is 3.69m for the 0.256 in. aperture,

nighttime scintillation should not reduce the transmission reading unless the central cone is smaller than predicted or is not uniform. Since the diameter of the central cone is only 0.88m for the 0.0081 in. aperture and 1.85m for the 0.0141 in. aperture, the transmission reading should be reduced by scintillation and the spread from maximum to mini-[?]mum should be increased because the receiver would more often be illuminated by the energy from outside the central cone. The reading is reduced, but the spread is not increased; in fact, the spread is reduced. This also is explicable if the central cone is smaller than predicted. Finally, consider table III. If the central cone were as large as predicted, whenever the transmitter is aligned with one window, the transmission reading should be the same at the adjacent window as long as the central cone covers both windows. This is not the case; and, in fact, the transmission reading is still 37 per cent lower even when the central cone should be 22m (G.141 in. aperture).

The above comments are applicable to the data from each window considered by itself. When the data from the windows are compared to each other, it is obvious that at night, window two consistently provided higher transmission readings than the other positions. This can be traced to ease of alighment; at the southernmost window (3) and on the stairs (4), the flexibility of the floor is such that when the individual aligning the receiver moves away from it, its boresight is shifted. Also, at the normal window (1), the receiver

mounts were such that it was very difficult to "tweak" the boresight to within \pm 0.5 mrad to assure maximum transmission readings.

Calibration Test

Results. The modified LOWTRAN program was run to plot transmission as a function of wavelength and dew point and visibility. Samples of the three spectral region runs using the rural aerosol model are shown in figures 7 through 11. These plots were used in conjunction with the manufacturer's spectral calibration data to select the wavelengths to be used for the calibration tests. The tests were not run until the night of 24 September because, at first, gaseous nitrogen was not available and then the weather was too hazy; recall, the tests must be accomplished when scattering is not the principle attenuation mechanism. Only the near IR was available the night of the test. The results of the measurements are included in table V along with the LOWTRAN predictions using the rural, urban, and maritime aerosol models. The meteorological conditions during the test are listed in table IV.

Parameter	B620	Trebein	Model
Temperature (°C)	18	15	16
Dew Point (°C)	13	14	14
Visibility (stat. mi)	12 (base wx)	8.5	8.5, 10, 12
Pressure (millibars)		985	985

Table IV. Meteorological Conditions During Cal Test

Table V. Spectral Transmission Data

No.

NOMINAL	MEASURED				OWTRAN	VISIBI	LITY (KN	()		
WAVELENGTH (µm)	TRANSMISSION	RUF 13.7	KAL MOI 19.3)EL 16.1	UR 13.7	BAN MO 19.3	DEL 16.1	MARI 13.7	TIME M 19.3	DDEL 16.1
1.69	71.5 ± 5.4	54.8	62.9	58.9	46.2	55.1		17.0	27.4	
1.73	64.0 ± 6.2	44.0	50.2	47.0	36.9	44.3	40.6	13.6	21.8	17.3
2.23	67.7 ± 6.2	66.8	73.1	70.0	56.4	64.8	60.5	21.5	32.7	26.7
2.27	66.2 ± 6.0	68.1	74.3	71.2	57.6	66.0	61.8	22.2	33.5	27.4
3.99	64.4 ± 6.2	54.8	58.5	56.7	50.1	54.9	52.5	21.4	30.0	25.5
4.03	60.7 ± 3.7	50.8	51.2	52.5	46.5	50.9	48.7	20.0	28.0	23.8
4.05	56.0 ± 5.2	47.4	50.5	49.0	43.4	47.5	45.5	18.8	26.2	22.3
4.62	19.5 ± 2.8	26.0	27.7	26.9	24.2	26.3	25.2	11.6	15.6	13.5
4.67	26.2 ± 2.8	30.5	32.4	31.4	28.3	30.8	29.6	13.7	18.4	15.9

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Fig. 9. Middle IR Spectral Transmissicn for Several Visibilities and Water Vapor Contents

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Fig. 10. Middle IR Spectral Transmission for Several Visibilities and Water Vapor Contents

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After the *in situ* tests were completed, the near IR receiver and the electronics unit were brought to building 620. The dust cover was removed from the transmitter assembly, and the receiver was installed on an adjustable mount looking directly into the transmitter assembly. The calibration procedure of Appendix B was followed. Precision control of azimuth and elevation pointing angles was not possible; consequently, a great deal of time was required for each alignment, and the final alignment was still questionable. The temperature of the IR blackbody is not monitored by the control electronics; it did not look as deep red as during the *in situ* tests. The highest transmission reading for the CAL aperture, with the 10X attenuator in place, was 7.8 per cent. Moving the electronics drawer never caused the reading to exceed 20 per cent.

Discussion. With one exception $(1.73\mu m)$ the measured transmission values in table V are within 0.1 of the predicted values using the base weather visibility and the rural aerosol model in LOWTRAN III B; the lower lo limit for that one wavelength interval is also within 0.1. Consequently, the calibration check in building 620 should have confirmed that no recalibration was required; this was not the case. Unfortunately, the adjustable mount was too difficult to use and an accurate alignment could not be proven. In addition, the variable transmission reading as a function of electronics drawer position caused much uncertainty in the procedure. Insufficient time remained to procure another mount and to

repeat the experiment to demonstrate the efficacy of the *in situ* calibration check. The drawer position problem was subsequently traced to a faulty ground.

V. Observations and Recommendations

Observations

Using the Transmissometer. Because the transmitter beam central cone is not as large as expected, both the transmitter assembly and the receivers should be aligned prior to each test. Unfortunately, this will restrict test operations to days in which the visibility is five miles or greater. If the present transmitter mount proves to be sufficiently stable so that the realignment is not required, test days will still be restricted to those on which the transmission is greater than three per cent. This is because over half of the visible and almost half of the near IR channels have such low filter factors that the indicated transmission will be less than one per cent and the receiver will lose synch.

Also, scintillation appears to have a strong effect on the measurements. The frequency and amplitude of its effects are such that single point, instantaneous sampling could lead to an incorrect value.

<u>Calibration</u>. Although the current through the visible source is monitored and is constant, the radiation output will still change as the source ages. This leads to the need to recalibrate all three receivers, not just the visible receiver.

The temperature, dew point and visibility values at building 620, the Trebein site and Patterson field differ enough that more samples should be used, and the LOWTRAN calculation should be accomplished by steps between the sampling points.

Recommendations

 Use receiver mounts with precision azimuth and elevation controls similar to those for small astronomical telescopes.

 Use a rotary table with the same kind of mounts for calibration.

3. Permanently mount and boresight a high power telescope on top of the transmitter assembly. This will permit alignment without removing the IR source and beam splitter.

4. After three is accomplished, conduct a beam uniformity test and repeat the tower test.

5. Monitor the IR source temperature.

 Provide an external synch for the receiver electronics.

7. Monitor temperature, dew point and visibility at all three meteorological instrumentation positions and, when using LOWTRAN, calculate the path transmission incrementally.

8. Determine the temperature/dew point variance along the path to determine if additional weather towers are required.

9. Verify the manufacturer's filter wheel spectral calibration and spectral resolution.

10. Conduct *in situ* calibration tests every time the visibility is greater than 15 km; use the data to select the most appropriate aerosol model; rural, urban or none; to use for the calibration graphs in Appendix B.

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Appendix A

Source Listing: Modified LOWTRAN IIIB

000180 000110 000120 000140 000150 00110 001190 000210 000290 002000 000310 000360 000380 00100 000130 000160 000200 000220 000240 000270 000300 000320 000330 0 0 0 3 4 0 000350 000370 000390 000410 06430 000230 000250 000260 001000 000420 0 1 1 0 0 0 DIMENSION C1(2580), C2(1575), C3(540), C4(133), C5(15), C8(102) DIMENSION VX(45),C7(45),C74(45) PROGRAM LT3HM (INPUT, OUTPUT, TAPE72, TAPE82, TAPE6=OUTPUT) DIMENSION TR(67), FW(67), FO(67), HZ(2), TX(10), W(10) F(A) = EYP(18.9766-14.9595+A-2.43882+A+4) *A PRINT*, "ENTER, IHAZE; JP, JSPEC, JTTY (413)" READ(82,431) (VX(I), C7(I), C7A(I), I=1,44) (TR(I), FW(I), FO(I), I=1, 57) PRINT 431, (VX(I), C7(I), C7A(I), I=1, 44) READ 431, (VX(I), C7(I), C7A(I), I=1, +4) IF(JP.LE.2.AND.JSPEC.E0.1)60 T0 903 IF (JP. CT.2. AND. JSPEC.ED.2) GO TO 903 IF (JTTY.EQ.1.AND.IHAZE.ED.7) IHA7E=1 DATA H7(1)/5H23 KM/, H7(2)/5H 5 KM/ DIMENSION HZ1(34), HZ2(6), EH(10) (C1(I),I=1,2580) (C2(I),I=1,1575) READ*, IHAZE, JP, JSPEC, JTTY PRINT 400, IHAZE, JP, JSPEC, JTTY (C3(I),I=1,540) (C4(I),I=1,133) READ (82,401) (HZ1(I),I=1,34) (C8(I), I=1, 102) (C5(I),I=1,15) (HZ2(I), I=1,5) IF(IHAZE.NE.7) GO TO 250 IF(JSPFC.NF.2)G0 T0 107 H72(6) = H21(6)READ (P2,401) (12,403) (82,404) (82,404) (82,404) (82,405) (82,405) (82,404) I = 3ZHIREWIND 72 RCTR=0.0 CONTINUE CONTINUE JCNTR=C READ U=XXJ DEAD READ PEAD READ READ DEAD 050

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PRINT+,"FNTER H1,P,TMP,DP,RH,WH,VIS,RANGE(KM,MB,C,C,%,GM M-3,KM,KM000520 PRINT 430, H1, P, TMP, DP, RH, WH, VIS, PANGE READ+ , H1 , P, TMP, DP, PH, WH, VIS, RANGE IF(7.6f.50.0) J=(Z-50.6)/20.0+31. AHAZE=HZ1(J)+(HZ1(L)/HZ1(J))++FAC AHZ2=HZ2(J)*(HZ2(i)/HZ2(J))**FAC IF(Z.6F.70.0) J=(7-70.0)/30.0+32 IF(7.6F.25.0) J=(7-25.0)/5.0+26. PRINT*, "ENTER, V1, V2, DV (CM-1)" FAC=(2-5.0*FL0AT(J-26)-25.)/5. IF(J.6F.31) FAC=(Z-50.0)/20.0 IF(J.6F.32) FAC=(7-70.0)/30.0 PRINT 0,07,41,RANGE IF(VIS.61.0.0) PRINT 417,VIS [F(JTTV.EQ.0)60 TO 510 IF(IXY.GT.3) 60 TO 541 IF (JTTY.EQ.0) GO TO 251 IF(FAC.6T.1.0) FAC=1.0 IF(J.LT.26) 60 TO 500 IF(Z.GF.5.0)60 TO 520 IF(IXY.6T.2)60 T0 542 IF(IXY.NE.3)60 TO 107 J=IFIX(7+1.0E-6)+1. PRINT 406, V1, V2, DV FAC=Z-FLOAT (J-1) RANGE=PANGE+1.0 IF (J. 61.33) J= 33 PEAD+ , V1 , V2, DV PCTR=RCTR+1.0 60 10 105 CONTINUE CONTINUE L=J+1 7=H1 : 1 107 231 000 220 110 242 145

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0 1 2 0 0 0 000750 000760 017000 000780 062000

000530

000480 064000 00200 000510

000450 000460 024000

IF (VIS.LF.0.0.AND.IHAZE.GT.0) PRINT 416, IHAZE, HZ (IHAZE) IF (VIS.LT.2.0.AND.VIS.GT.0.0) PRIVI 442 IF (IHAZE.FQ.0.) PRINT 426 PRINT 418, V1, V2, NV, ALAM, AVW CW=43 .- 87-0.3473*AVW IF (JSPFC .En. 1) LA X3=4 TF(JSPFC.E0.1) LAX2=4 IF(JP.(E.2)G0 T0 14 IF(JP.(T.3)G0 T0 13 IF(II.F0.1)60 T0 15 AVW=6 . E -4* (V1+V2) WVA+65+.451.77=00 00 969 II=1,LAX1 ALAM=1(000./V2 AVW=10000./V1 TMP=TMP-20.0 TMP=TMP+20.0 AVW=AVW*AVW 0.2-SIV=SIV 0. 2-90=90 GO TO 14 CONTINUE 5UMR=0.0 SUMV= 0.0 CONTINUE 0.0=WMU? LAX1=3LAX1=1LAX3=7 LAX2=7 L A X 2= 1 L A X 3 = 1 L A X 1 = 1 L = X Z = 1 L A X 3= 1 4 8 1 3 14

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001020

HA7E=6.389*((AH22-AHA7E)/VIS+AHAZE/5.0 -4H72/23.0) EH(5) = 0+PPW+EXP(6.08+(TS1-1.0))+0.002+0+(PS-PPW) EH(10)=0*(PPW+0.12*(PS-PPW))*EXP(+.56*(TS1-1.0)) IF (RH.LE.0.0) TT= 273.15/ (273.15+0P) IF (RH.GT.0.0) WH= 0.01 * 3H+WH IS1 = (296.0/273.15)*TS F(VIS.LF.0.0) 60 TO 150 IF (HAZF.LT.0.0) HAZE=0.0 IF (JSPFC.E0.1) 0P=0P+23.0 IF (IHA7E .EQ.2) HAZE = AH72 PPW=4 .56E-5+0+27 3.15/TS IF(Z.6F.5.6) GO TO 150 [F(JP.F0.3) VIS=VIS+5.0 IF (WH .LE .0.0) WH=F (TT) IF(IXY.E0.1)60 T0 49 TF(JP.FO.4)WH=F(TT) FH(7) = HAZE/AHA7F 00 909 KK=1, LAX3 EH(2)=X+PT++0.75 00 909 JJ=1,LAX2 EH(1)=0+PT++0.9 EH(4) = 0.8*PT*XPT=PS+S0RT(TS) T=TMP+273.15 PS=P/1013.0 11=273.15/1 TS=273.15/T HAZE=AHAZE 0P=0P-25.0 W0=5.6F-05 0+ 3+ d0= d0 CONTINUE 0=0.1+WH SI +Sd=X FH (6) = X 150 15

001240 001330 001340 001160 001170 001190 001210 001220 001230 001250 001250 001280 001300 001310 001320 001350 001360 001380 001390 001400 001420 001450 001180 001200 001270 001290 001370 001410 001430 001440 001460 01470 001490 001490

001150

001510 001560 001570 001770 001520 001580 001590 001500 001510 001520 001630 001640 001650 001660 001670 001680 001590 001100 01710 001720 001730 011740 001750 001790 001800 001910 001500 001530 0 0 1 5 4 0 001550 001760 001790 001820 001830 001840 IF (JSPFC.EQ.1.0R. (JJ.EQ.1.AND.KK.EQ.1)) WRITE (72) TMP, 0P, VIS IF(II. FO.1. AND.JJ.EQ.1. AND.KK.EO.1) ARITE(72) JSPEC, JP, N BEGINHING OF TRANSMITTANCE CALCULATIONS REF= 1.0E-6+ (CO+X+1013.0/273.15-PPA+CW) [F(JP.F0.2.0R.JSPEC.E0.1)60 T0 51 IF (IV2.6T.50100) IV2=50000 IF(ICOUNT.EQ.50) ICOUNT=0 F (IV1.LT.350) IV1=350 IF (ICOUNT.EQ.0) PRINT 422 1=FLOAT (JV2-IV1) /DV+1 IF (K.LT.4) TX(K)=1.0 FH(3)=FH(8)*PT**0.4 [F(JP.FO.0)60 TO 51 IF (DV.LT.5.) 9V=5. EH(8)=46.6667*W0 W(K)=RANGE*EH(K) JCNTR=JCNTR+1 [V2=V2/5.+.99 no 27 K=1,10 00 53 X=1,10 [V1=V1/5.0 IV=IV1-INV EH(9)=1.0 IV1=5+JV1 VOI+VI=VI TX (K) = C . C [V2=5*JV2 G0 T0 F2 ICOUNT=0 SUMA=0.0 CONTINUE CONTINUE 10=101 1=1 1=1 64 105 15 ***** 0 5 25 E.

TX (8) = C8 (NN) + XD* (C8 (IIN) - C8 (NN-1)) POLECULAR SCATTERING 25 IF (IV.LT.13030) GO TO 69 87 C6=9.807E-20*(V**4.0117) IF (IV.LT.9200) G0 T0 72 IF(IV.LE.3000) GO TO 61 10 IF (IV.GE.27530) GO TO 60 70 F(IV.LT.676) 60 T0 72 XI=(V-27560.0)/XX+57.0 XI=(V-13000.0)/XX+1.0 60 TX (8) = M (8) + C8 (NN) IF (IV.67.14500) TX (8) = H (8) + TX (8) IF (IV.LE.23400) F (X0) 59,58,57 COUNT = I COUNT +1 XD=XI-FLOAT (NN) =(IV-350)/5+1 00 57 NN=L1,L2 3****** UV 020NE TX (6) = C6 * W(6) SUM=SUP+TX (6) SUM=SUM+TX(8) CONTINUE 60 10 16 50 TO FO XX=200.0 GO TO 87 XX=500.0 3.0=MU2 L2=102 2=53 L1=57 VI=V L1=1 ******** 5 .. 8 5 5 0 0 t -

001960 01970 001980 001990 001900 001920 001930 001943 001350 001960 01970 001980 001990 002000 002010 0 5 2 0 2 0 002030 0 0 2 0 4 0 002050 002060 0 0 2 0 7 0 002080 002000 002100 002110 002120 002130 002140 002150 002160 002170 002180 002190 001850 01910

TX(5) = (4.18 + 5578.0 + EXP(-7.875-3+V)) + W(5)WATER VAPOR CONTINUUM 10 41333N RESION 4 MICRON REGION IF (IV.LE.14520.AND.IV.GE.13400) 63 73 71 IF (IV.LT.128J0.AND.IV.GE.9875) G0 T0 70 IF(IV.LE.1350.0R.IV.GT.2740) G0 T0 72 TX(5)=TX(5)+XH*(C5(NH)-C5(NH-1)) = (V-2350.0) / FU.J + 1.0 IF (W(1).LT.1.0E-20) GO TO 76 F (WS1.LT.-2.3466) 60 T0 76 (WS1.6T.3.5682) 60 T0 75 3****** WATER VAPOR CONTINUUM NITROGEN CONTINUUM IF (IV.LT.2030) 60 TO 72 IF(IV.6T.1350) 60 TO 62 IF(IV.LT.2350) GO TO 68 WS1=AL0610(W(1))+C1(I) (WS1.6T.2.3) K1=40 NH = XI + 1.001XH = XI - FLOAT(NH)TX(5)=TX(5)*W(10) WATER VAPOUR SUM = SUM + TX(5)(+) H+ (+) +) = (+) X (+) TX(5) = C5(NH)SUM=SUF+TX(4) 73 K=K1,67 G0 T0 66 K4=I-316 G0 T0 72 50 10 76 50 TO 72 50 TO 19 [= I-1 3F I=1-251 ***** **** K1=1 X ******** FF 00 4 IX *** +++0 6.3 55 51 80 60 20 10

002200 002210 0022200 002230 0 0 22 4 0 002250 002260 0 0 2 2 7 0 002280 002290 002300 002310 02320 002330 002340 002350 002360 002370 002380 002390 002400 002410 002420 002430 0 0 5 4 4 0 002450 002460 002470 002480 002490 002500 002510 002520 002530 0 0 52 4 0

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002700 002560 002580 002500 0 0 25 4 0 002650 002570 002690 002710 002720 0 7 2 0 0 002750 002760 002770 002780 002910 002820 002839 002850 0 0 2 5 5 0 0 0 2 5 7 0 002590 002510 002620 002530 002660 002630 002730 002790 002800 002840 002960 002870 002880 002890 TX(1)=TR(K)+(TR(K-1)-TR(K))+(FW(K)-431)/(FW(K)-FW(K-1)) TX(2)=TR(K)+(TR(K-1)-TR(K))+(FW(K)-4S2)/(FW(K)-FW(K-1)) 78 C****CALCULATED FOR Z.LT.2 WITH WO.ED.5.5E-D5 13 17 IF (IV.LT.575.0R.IV.GT.3270) 60 T0 87 IF (IV.LT.8060.AND.IV.GE.500) G0 T0 IF (IV.LT.13190.AND.IV.GT.12970) G0 IF (W(3).LT.1.0E-26) 60 TO 87 (WS2.LT.-2.3466) GO TO 83 IF (WS3.LT.-1.6778) GO TO 87 TF (WS3.GT.3.9345) GO TO 86 UNIFORMLY MIXED GASES TF(W(2).LT.1.0E-20) 60T0 83 (WS2.GT.3.5682) G0 T0 82 IF (WS1.LE.FW(K)) 60 TO 74 IF (WS?.LE.FW(K)) GO TO 81 WS3=ALCG10 (W(3)) +C3(L) WS2=AL0610(W(2))+C2(J) IF (WS2.6T.2.0) K1=40 J=(IV-12950)/5+1516 30 K=K1,67 070NE T X (1) = 0.0TX(2) = 0.062 01 05 CONTINUE 50 TO F3 CONTINUE 60 10 76 GO TO 83 CONTINUE CONTINUE J=I-30 24-I=1 ******** K1=1 K1=1 *** 41 00 L 82 81 23 14 50 -11 200

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0 0 2 9 3 0 0 7 6 2 0 0 002960 0 2 6 2 0 0 002980 066200 003000 003020 003030 0 0 30 4 0 0 0 3 0 5 0 0 0 3 0 6 0 0 0 3 0 7 0 0 0 3 0 9 0 0 0 3 0 9 0 003100 003110 003130 003140 003160 003180 003200 003220 0 0 32 4 0 002300 0 0 29 1 0 026200 002950 003010 003120 003150 003170 003190 003210 003230 TX(3)=TR(K)-(TR(K)-TR(K-1))*(F0(K)-453)/(F0(K)-F0(K-1)) × W YY= (C76 (NN) - C74 (NN-1)) * XD/ (VX (NN) - VX (NN-1)) + C74 (NN) ~ XX = (C7 (NN) - C7 (NN-1)) + XU/(VX (NN) - VX (NN-1)) + C7 (NN) BELOW XX = 3.91/VISVIS FOR COPRECTION TX(K)=1.0-TX(K)+0.5+TX(K)+TX(K) IF (VIS.67.0.0.AND.VIS.LT.2.0) 93 IF (WS?.LE.FO(K)) GO TO 85 26 AFROSOL EXTINCTION 10 60 T0 60 10 IF(IHA7E.EQ.0)G0 TO 90 IF(XX.GT.0.0)G0 T0 90 (WS3.6T.1.5) K1=36 0 5 F 06 (TX(K).EQ.0.0) (TX(K).LE.0.1) (TX(K).6T.20.) [X(K)=FXP(-TX(K)) ***** TEMPORARY IF (XD) 69,88,88 XD=ALAM-VX (NN) 34 K=K1,67 00 96 PIN=1,44 AL AM= 1.0 E+4/V (2) = X X * W(7)(1) X1+HUS=HUS 94 K=4,10 WOS= (6) X1 TX (3) = C . C TX(K)=1.0 CONTINUE CONTINUE 50 TO 94 50 TO 94 GO TO 87 CONTINUE YY=0.0 $0 \cdot 0 = X X$ *** 00 00 L L L L 99 06 38 + ** * 1 10 50 16 C.E

60 TO 64	003250
TX(K)=0.	003260
CONTINUE	003270
SUMV = SUMV + TX (7)	003280
H0H=TX(1)+TX(5)	003290
IF(JP.E0.2.AND.JTTY.EQ.1)WRITE(6,4+3) 40H	003300
HOH+MWINS = MMNS	003310
TX(10)=1.0-TX(10)	003320
TX(9)=TX(1)+TX(2)+TX(3)+TX(9)	003330
IF (IV.GE.13006) TX(3)=TX(8)	003340
AB=1.0-TX(9)	003350
IF(IV.FO.IV1.OR.IV.EQ.JV2) AR=6.5+49	003360
SUMA=SIIMA+AB+DV	003370
IF(JP.FQ.0.0R.JP.E0.2)WRITE(6,423)IV,ALAM,TX(9),(TX(K),K=1,7),	003380
1 TX (10), SUMA	003390
TF(JSPEC.E0.1)WRITF(6,423)IV,ALAM,TX(9),(TX(K),K=1,7),TX(10),SUM	003400
TN=TX(9) +100	003410
IF(JP.EQ.2)WRITE(72)ALAM,TN	003420
IF (JSPFC.EQ.1)WRITF (72) ALAM, TN	003430
IF (IV.GE.IV2) 30 T0 95	003440
G0 T0 ± 0	003450
95 AB = 1.0 - SUMA/ FLOAT(IV2-IV1)	003460
PRINT '24, IV1, IV2, SUMA, AR	003470
PRINT*,"TMP=",TMP," 0>=",0P," VIS=",VIS," J>=",JP," JSPEC=",JSPEC	003480
PRINT*, "PANGE=", RANGE	003490
IF(JP.LT.2)60 T0 909	003500
PRINT*, "N=", N	003510
N/MHIS=MMNS	003520
N/AMAS=AMAS	003530
IF (SUMV.LE.0.0) PRINT*, "SUAR WON'T 204PUTE"	0 0 32 4 0
SUMR=0.949	003550
IF (SUMV. GT. 0. 0) SUMR=A3/ (SUMV*SUMW)	003560
PRINT 445, SUMM	013570
PRINT 446, SUMV	003580
PKINI 447,50MK	066600

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IF (RANGE.GE.25.0.0R.A3.LE.0.0001) 53 T0 106 IF (JTTY.EQ.1) PRINT*, "ENTER IXY (I3)" IF (JS PFC . ED. 2) RANGF = RANGE - RCTR (CM-1). IF (JP . EQ . 3) WRITE (72) VIS, SUMV GO TO (96,2,107,97,100), IXY PRINT 418, V1,V2, DV, ALAM, AVW IF (JP.EQ.4) WRITE (72) DP, SUMW IF (JSPFC.EQ.1) VIS=VIS+15.0 IF(JSPFC.NE.2)60 T0 106 IF (JSPEC.E0.1)60 T0 686 PRINT*, "ENTER V1, V2, DV PRINT*, "JCNTR= ", JCNT? PRINT*, "IXY= ", IXY IF(IXY.FO.0) 60 TO 100 IF(JTTY.EQ.J)60 T0 787 IF(IXY.E0.1)60 T0 48 2 IF (JP.LE.2)60 TO 48 TF(JP.NE.3)G0 T0 98 IF(IXY.E0.4)60 T0 READ+ , V1, V2, DV ALAM=11000./V2 VMUS+001=VMUS WWNS+0 JT=MWNS AVW=10100./V1 0.05-21V=21V READ 400, IXY GO TO 250 CONTINUE RCTR=0.0 CONTINUE SUMR= 0.0 SUMV=0.0 0.0=WMUS CONTINUE IXY=3 96 606 106 989 187 51

003200 003610 003620 003630 003650 0 0 36 60 003680 003700 003710 003720 003730 0 0 37 4 0 003750 003760 003770 003780 003800 003810 003820 003830 0 0 3 8 4 0 003860 003880 003900 0 7 9 2 0 0 003670 003590 062200 003850 003870 0 0 3 8 9 0 003910 026200 003930 0 9 6 2 0 0

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N.

+30 FORMAT(10X," INPUT METEROLOGICAL DATA"/10X,"Z=",F7.2,",KM, P=",F7.004220 12,*MB, T=*,F5.1,*C, 0EW PT=*,F5.1,*C, RH=*,F5.1,*X, WH=*,E10.3,*GM004230 0 0 4 0 4 0 FORMAT (/10X,21H FREPUENCY RANGE V1= , F7.1,13H CM-1 TO V2= , F7.1,1004130 H20,5X4HC02+,5X,6004150 INTEGRATED004160 ABSORPTION) 004170 424 FOPMAT(/* INTEGRATED ABSORPTION FR34*,15,* TO*,15,* CM-1 =*,F10.2,004190 ++2 FORMAT(* FOG CONDITIONS MAY EXIST AT SEA LEVEL FOR THIS VISUAL PAD04260 INGE*, /, IF SO THEN ASSUME THE TRANSMITTANCE DUE TO FOG IS GIVEN 004270 0 0 3 9 5 0 003960 0 2 3 9 7 0 003980 066200 004000 0104010 004020 004030 004050 004060 0 1 0 1 0 1 0 004080 060400= 004100 004110 004120 004140 004180 004200 004210 004240 004250 004280 004290 (/25X+HAZE MODEL =+,F5.1,+ <M VISUAL RANGE AT SEA LEVFL+) (//10X,28H HORIZONTAL PATH, ALTITUDE =, F7.3,12H KM, RANGE (, =5.3, * - *, F6.3, * MICRONS) *) 416 FORMAT (/20X,12H HAZE MODEL ,11,3H = ,45,13H VISUAL RANGE) +26 FOPMAT (/20X,*AEROSOL SCATTERING NJT JOMPUTEN,IHA7F=0*) AEROSOL 2 /11X,14H CM-1 MICRONS, a (4X,5HTRANS),4X,20H ARS 422 FORMAT (1H1,/10X, 32H FREQ WAVELENGTH TOTAL N2 CONT H20 CONT MOL SCAT AFROSD. 2 M-3, VIS RGE=*, F6.1, *KM, RGE=*, F10.3, *KM*) 28Y THE TPANSMITTANCE AT 0.55 MICRONS.*) 1*, AVEFAGE TRANSMITTANCE=+,F7.5) 14H CM-1 FOP DV =, F6.1, 9H CM-1 423 FORMAT (10X, 16, 10F9.4, F12.2) IF (JSPFC.EQ.1) DP=DP+5.0 FORMAT (4(F6.2,2F7.5)) (4(F6.3,2F7.4)) IF(IXY.EQ.1)60 TO 48 2 2 IF(IXY.E0.4)60 TO FORMAT(1013, F10.3) IF(JP.NE.4)50 TO FORMAT (8E10.3) (15F5.2) (7F10.3) (8E9.2) 443 FOPMAT (2F7.3) 1, F7.3, 3H KM) TMP=TMP-40.0 0-01-40=40 14H070NF FORMAT 0 · 0 = HM FORMAT FORMAT FORMAT FORMAT FORMAT STOP 98 100 00% 12 1 117 101 204 000 413 504 101 101

004300 004310 004320 004330 004340 004350 FORMAT(F5.1,F7.3) FORMAT(/9X,34H AVERAGE WATER VAPOR FRANSMISSION=,F7.5) FORMAT(/9X,34H AVERAGE AEROSOL TRANSMISSION =,F7.5) FORMAT(9X,34H AVERAGE MOLECULAR TRANSMISSION =,F7.5) FORMAT(9X,26H WATEP VAPOR TRANSMISSION=,F7.5) FORMAT(9X,26H WATEP VAPOR TRANSMISSION=,F7.5) FORMAT(9X,26H WATEP VAPOR TRANSMISSION=,F7.5) ***

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Appendix B

Draft Calibration Handbook

for

Barnes Model 14-WP Transmissometer

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GEP/PH/77-14

As designed, the Barnes transmissometer is expected to require recalibration at three month intervals. Because of the difficulty of bringing the receiver and electronics to the transmitter assembly for calibration, it is desirable to use the transmission measurements themselves to determine when recalibration is required. This appendix discusses a technique for accomplishing this and then provides a step by step description of the calibration procedure.

Determine When Calibration is Required

The transmission measured by the Barnes Transmissometer can be separated into the transmissions of 3 different constituents of the atmosphere, the aerosols, the water vapor, and the remaining molecular absorption.

^TTotal ^{= T}Aerosol ^X ^TH₂0 ^X ^TMol The aerosol transmission, ^TAerosol, is a function of visibility, VIS. The water vapor transmission, ^TH₂0, is primarily a function of the dew point temperature, T_{Dew} , with a minor temperature dependence. The transmission by the other molecular absorbers can be considered a constant with a very weak temperature dependence. Given a knowledge of the visibility, dew point temperature, and the air temperature, it is possible to predict, within a few percent, the expected values of the transmission for each of the receivers of the Barnes Transmissometer. Figures B-1 through B-18 permit making these predictions. Figures B-1 through B-6 are for the visible receiver, B-7 through B-12 are for the near-IR

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receiver and B-13 through B-18 are for the far-IR receiver. The following steps should be accomplished for each spectral band as indicated on the figures.

1. Using the visibility figure, find the predicted aerosol transmission, $\tau_{aerosol}$.

2. Using the dew point figure, select the temperature curve closest to the ambient temperature and find the predicted water vapor transmission, $\tau_{\rm H_2O}$.

3. Using the curve labelled $\tau_{\mbox{Mol}}$, find the predicted molecular transmission.

4. The expected transmission for the appropriate wavelength is then the product of the three constituent transmissions.

 $\tau_{\text{Expected}} = \tau_{\text{Aerosol}} (\text{VIS}) \times \tau_{\text{H}_20} (\tau_{\text{Dew}}) \times \tau_{\text{Mol}} (T)$

5. If the measured transmissions are more than 0.1 lower than the expected transmissions for good visibilities (10 to 20 kilometers or better), the Barnes Transmissometer should be recalibrated.

Calibration Procedure

1. Remove the dust cover from the transmitter assembly

2. Mount the receiver to be calibrated onto a small rotary table and place the assembly on the telescope bed. <u>CAUTION</u>. Do not bump the spider mirror.

3. Assure that the receiver optics are looking entirely into the telescope mirror. Use a sheet of white paper in front of the entrance aperture to confirm this.

4. Install the 10X attenuator in connector J2 on the mother board of the electronics unit for the receiver being calibrated.

5. Place the system in normal operation and use the JOG button to select the filter wheel position to the maximum response position as indicated in the manufacturer's calibration data book.

6. Select the 0.1405 inch aperture.

7. Rotate the receiver slowly in azimuth and elevation to produce the highest indication first on the ANALOG ALIGNMENT meter and then on the PERCENT TRANSMISSION digital readout indicator.

8. Lock the position settings on the Receiver Assembly.

9. Set the aperture wheel on the source to the next smaller setting and repeat Steps 4 through 8. Continue to repeat this procedure with smaller and smaller aperture settings until the one marked CAL is in position, then lock the rotary table.

10. On the Receiver, adjust the PHASE CONTROL knob to produce the maximum reading on the ANALOG ALIGNMENT Meter.

11. Observe the indication on the PERCENT TRANS-MISSION display. If it is not 37.3, proceed to Step 12.

12. Unlatch the lower right panel in the receiver electronics unit and slide the chassis forward. Locate the calibration screwdriver adjustment at the upper right of the circuit board as seen from the component side. Rotate this

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adjustment to produce a reading of 37.3 on the PERCENT TRANSMISSION digital display. Approach the 37.3 indication slowly by going up through lower indications and stopping as soon as 37.3 appears on the display.

> At this point, the receiver is calibrated for the wavelength of maximum signal "Thru-put". Next, a printer is interfaced to the computer output connector. At each stopping position (wavelength), the BCD position is recorded along with the voltage displayed on the panel meter. The filter drive must be in AUTO mode. From this printout the factors are determined which will be used to normalize the data at each wavelength for a 37.3 reading with no path attenuation.

 Recalibrate the other two receivers by using the same procedure.

14. The Atmospheric Transmissometer System is now recalibrated and can be placed back into normal use once the radiation source aperture wheel is returned to its initial position.









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Fig. B3. 0.87 um Transmission as a Function of Visibility and Water Vapor Content

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Leo Owen Vroombout was born 6 September 1940 in Camden, New Jersey. He graduated from Merchantville High School in 1958 and attended Princeton University where he was awarded a Bachelor of Arts degree in Physics in 1962. After graduation, he attended AFROTC summer camp at Eglin AFB where he was commissioned on Friday, 13 July 1962. He began active duty in September, 1962 in the Aeronautical Systems Division (ASD), Wright-Patterson AFB, Ohio. After five years of developing and flight testing infrared and laser imaging systems, he was transferred to the Minuteman SPO, SAMSO at Norton AFB, CA. At Norton, he was the Reentry Vehicles Survivability/Vulnerability Staff Officer until he left active duty in May, 1969. He returned to ASD as a civil servant and continued his career as an electronics engineer responsible for developing infrared imaging systems. After participating in the combat evaluation of an infrared reconnaissance system in Southeast Asia, he began work for the Air Force Avionics Laboratory (AFAL) in 1973. At AFAL he became responsible for the Air Force Second Generation FLIR program and continued in that position until entering the School of Engineering, Air Force Institute of Technology, in June 1976.

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