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METEOR BURST COMMUNICATION SYSTEM --ALASKA WINTER FIELD TEST PROGRAM

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UNITED STATES
DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
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National Weather
Service
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PREFACE

The Winter Test Program of the Boeing Meteor Burst Telemetry System was supported by five Federal Agencies under Contract No. 03-5-027-004 between the National Weather Service (contract agency) and the Boeing Aerospace Company. The results of this Program as prepared by Boeing in fulfillment of the contract are presented in the report entitled Meteor Burst Telemetry Winter Test Program - Test Report, Boeing Aerospace Company Document No. D182-10423-1.

In addition to the above mentioned report, the Alaskan River Forecast Center, National Weather Service (NWS), performed its own analysis of the system using the raw data obtained during the test program. This analysis was separate from that performed by the Boeing Company. The results of the NWS analysis and the conclusions drawn from the findings are those of the National Weather Service and do not necessarily represent the feelings of the other agencies participating in the Test Program. The use of manufacturers' identification on equipment used is merely for easy reference and no endorsement nor criticism is implied or intended.

In some instances, discrepancies will be noted between the findings presented in the report prepared by the Boeing Company and those presented in this report. However, it should be noted that although the basic raw data used in both analyses were the same, the method of reduction, the primary statistic, and the methods of analysis were completely different. Thus, resulting discrepancies could be anticipated.

ACKNOWLEDGEMENT

The National Weather Service is grateful for the support and cooperation of the numerous agencies and organizations which assisted with the Test Program upon which this report is based.

These organizations include:

- Alyeska Pipeline Service Company
- BP Alaska Oil Company
- Bureau of Land Management
- Corps of Engineers
- Federal Aviation Administration
- Soil Conservation Service
- U.S. Army Cold Regions Research and Engineering Lab.
- U.S. Forest Service, Institute of Northern Forestry
- U.S. Geological Survey

Obviously, agencies are composed of people, and it is really these field personnel and administrators we have to thank. Equally obvious, as a quick review of the report will show, they are too numerous to mention individually. It is the work of each and all of them that made this Program as productive as it was.

Stuart G. Bigler
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ALASKA WINTER FIELD TEST PROGRAM

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ABSTRACT. The Boeing Meteor Burst Communication System was tested in Alaska for a thirty day period beginning February 14, 1975. During the testing program the base station was located in Anchorage and remote field units were operated from Fairbanks, the Caribou-Poker Creeks Research Watershed (located approximately 35 miles north of Fairbanks), McGrath, Bethel, Kotzebue, Prudhoe Bay, Dietrich Camp, and Delta Junction with the first two stations serving as the primary source of the data. A total of approximately 40,000 messages were received by the base station from the various remote units.

The data were classified according to remote unit identification, date, time, and condition of the message. An analysis of variance was performed on the hourly groupings of data for the various stations. These comparisons indicated that: 1) no significant difference could be identified between the data from the beginning and end of the test period, i.e., the anticipated seasonal variation was not apparent; 2) a diurnal variation in the mean waiting time between consecutive good messages occurred such that a minimum value was observed between 09:00 and 10:00 AST and averaged 2.0 minutes; 3) the maximum mean waiting time between consecutive good messages occurred during the time interval between 17:00 and 18:00 AST and averaged 7.0 minutes; 4) the anticipated sinusoidal variation in the diurnal distribution of the waiting times between consecutive messages was not observed; 5) no conclusive statements can be made concerning the effects of distance on the distribution of waiting times between consecutive messages.

In addition to the studies involving an analysis of variance, the data indicates that: 1) the aurora borealis may have either an enhancing or a detrimental effect on the operation of the system; 2) the detrimental effects of the aurora result in a multipath communication which scrambles the message, such conditions were observed during approximately 11 percent of the hourly time periods; 3) the data sample obtained during the hourly periods when the adverse aurora effects were present represents nearly half of the total test data; 4) during aurora events, it took nearly 9 transmissions by the remote unit to get one good message through to the base station; 5) during non-aurora periods it took less than 2 attempts to get one good message through to the base station; 6) the system operated properly at temperatures below the specified the manufacturer's limit of -30°C; 7) no major malfunctions of the research equipment were encountered during the test program.

INTRODUCTION

In February-March, 1975, the National Weather Service, Alaska Region, participated with several agencies in a winter test program of the Boeing Company's Meteor Burst Communication System. The test program was supported by the National Weather Service (NWS); Bureau of Land Management (BLM); Federal Aviation Administration (FAA); U.S. Army Corps of Engineers (COE); Soil Conservation Service (SCS); and the U.S. Geological Survey (USGS). The NWS, Alaskan River Forecast Center served as the contract agent for the project and supervised the field operations and the general testing program.

The Boeing Meteor Burst Communication System (MBCS) utilizes meteor trails to reflect or reradiate VHF radio signals between the base station and a number of remote stations used for data acquisition or message communication points. During the operations, the base station transmits a coded message. If a meteor trail is in the proper location, the radio signal will be reflected to a remote station located at some distance from the base station. If the remote station has the address that the base station is trying to contact, then the remote station is switched from a receive to a transmit mode and the data or message from the remote is sent back to the base station along the same communication path. The entire process of the base station probing a remote unit, the remote interpretating the signal, switching to a transmit mode and transmitting the message takes place in approximately 20-60 milliseconds, depending on message length.

If the reflected signal should be received by a remote station which is of a different address or code from the one that the base station is trying to call, or if the reflected signal returns to the earth at a point where no station exists, then nothing happens and the base station keeps sending out its probing message until such time that the required response is obtained. Since there are only a limited number of locations where a meteor trail can be positioned such that it will provide the proper reflecting surface for any given remote unit, and further, since the occurrence of a meteor in one of these required locations is a random event, the communication between base station and any one remote station is of an intermittent nature reflected by the laws of probability.

Because of the earth's rotation about its axis and its elliptical path around the sun, the number of meteors which are potentially available for use as reflecting surfaces vary with the time of day and the season of the year. The diurnal variation is approximately sinusoidal with a high in the early morning and a low in the late afternoon. The seasonal variation is also approximately sinusoidal with a high in July-August and a low in January-February. With these combined variations, one would expect to find the lowest communication rate in late afternoon during January-February and the highest rate in the early morning hours during July-August. 1/

1/ *For further information on the operation of the Boeing MBCS, the reader is referred to: Leader, R.E., Meteor Burst Communication in Advanced Concepts and Techniques in the Study of Snow and Ice Resources, compiled by*

(Continued)

With these known variations in communication rates, the participating agencies wanted to test the system during the low period of operation and to determine if the system was capable of meeting the various communication requirements. The system had previously been tested during July-August, 1974 (the high point of the communication period) and demonstrated that it could more than adequately meet the communication requirements of the participating agencies during this period. 2/

There were also a number of other items such as environmental effects, remote antenna configurations, and others, which were of interest to the participating agencies. Thus, the following test program was established.

(Continued)

H.S. Santeford and J.L. Smith, National Academy of Sciences, Washington, D.C., 1974.

For a detailed discussion of the propagation phenomenon, see: Sugar, G.R., Meteor Burst Signal Distributions, NBS Report 7224, National Bureau of Standards, Boulder, Colorado, January 30, 1962.

Sugar, G.R., Radio Propagation by Reflection from Meteor Trails, Proceedings IEEE, 52:2, February, 1964, 116-136.

Proceedings of the IRE, 45:12, December, 1957, 1642-1740. (Special series of 12 papers and 2 letters to the editor)

2/ *Santeford, H.S., Meteor Burst Telemetry in Alaska, unpublished Field Test Report, NOAA/NWS, Anchorage, Alaska, September, 1974.*

OBJECTIVES

The primary objective of the winter test program was to evaluate the Boeing MBCS under winter conditions in Alaska and to determine if the system was capable of meeting the communication needs of the various participating agencies. To meet these objectives, the following secondary objectives were established:

1. To evaluate the season variation in communication rates between the July-August period and the February-March period.

2. To determine the effects of the Alaskan winter climate on the operation of the system.

3. To investigate the communication rate from various locations which were not studied during the summer test period program.

4. To determine the adaptability of the system to various NWS equipment such as the AMOS (Automatic Meteorological Observation System).

5. To investigate the effects of various antennas on the operation of the remote stations.

TEST PROCEDURES

The general procedure consisted of establishing a base station at the BLM offices at Campbell Air Strip, Anchorage, with remote stations located at various sites throughout the state. The base station was operated on a continuous basis.

A remote unit was located at the SCS offices in Fairbanks utilizing the same equipment and site location as used during the summer test program. Thus, this station provided the comparison between summer and winter test data. The station was interfaced with two NWS DARDC units which generated a 7-word message with each word containing four digits. Here, a fixed message was used in order that a comparison could be made between what was sent and what was received. This station was operated for the full period of the test program and is subsequently referred to as the "Fairbanks Station."

A second remote unit was installed on the Caribou-Poker Creeks Research Watershed (approximately 35 miles north of Fairbanks) and operated as the Environmental Test Station. The station consisted of a Boeing Hydro-Met unit with sensors for monitoring the ambient air temperature, the temperature of the electronics, the charge on each of the two battery units, and a counter for recording each time the transceiver was switched into the transmit mode. A sixth data word called "status" was also provided which was a check on the operation of the individual sensors, i.e., if the sensors were performing properly, a message word consisting of six "Ø" would be printed out at the base station.

The original test procedure called for the electronics associated with the Environmental Station to be housed in an uninsulated shelter with the batteries buried in the snow pack. However, at the time of installation temperatures in the Fairbanks area were dropping to the -40°F range and thus exceeded the specified operational temperatures for the equipment (-22°F or -30°C). A change in procedures was thus made. The electronics package and the batteries were both buried in the snow pack in such a way that they were in direct contact with the relatively warm ground and covered with approximately 18 inches of snow for insulation. Figure 1 shows the initial installation. Here, only the antenna and the ambient air temperature sensor were fully exposed to the natural environment.

Shortly after installation, an operational problem was noted with this station. Upon investigation it was found that a battery lead was disconnected. However, to fully test the equipment and to assure that the loose battery lead was the sole source of the problem, the entire unit was removed from the snow pack and transported to the main field station on the Research Watershed for investigation. Following the testing it was decided to place the unit outside adjacent to the main field station instead of returning it to the snow pack. Thus if further operational difficulties should be encountered, the unit would be much more accessible for examination. There was, however, one major difficulty with the main field station site. Namely, a severe stream icing (aufeis) was occurring in the vicinity and consequently it was not possible to bury the batteries in the snow pack as no "snow pack" existed at the site. It was

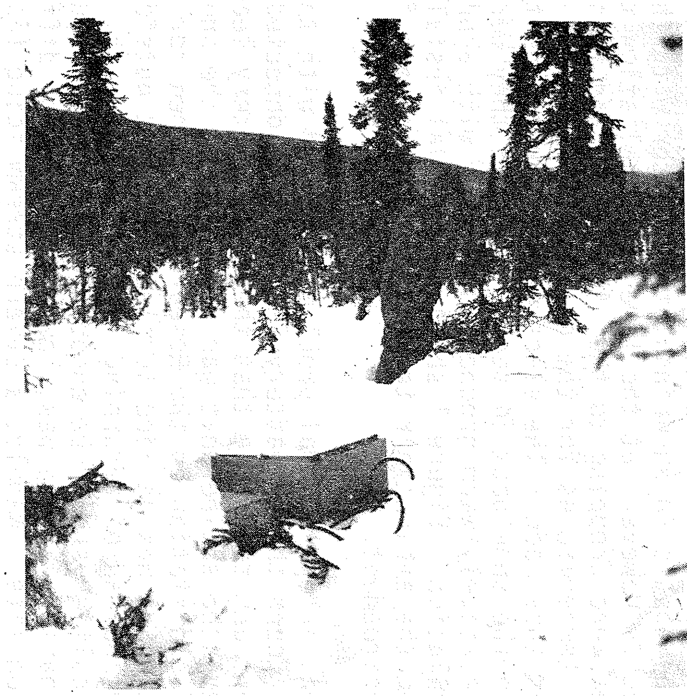


Figure 1 Initial installation of the Environmental Station.

therefore decided to leave the batteries inside the field station. If the unit operated as anticipated, and further, if the weather warmed sufficiently, the batteries were, at some later date, to be placed outside adjacent to the electronics unit. The revised site location for this installation is shown in Figure 2.

The project proposal called for the Environmental Station to be operated on battery power for the full test period. If the power drain became too great, the batteries were to be removed and temporarily placed on a charger. By equipping the station with sensors on the batteries, and also a counter on the number of transmissions that were made, it would be possible to adequately determine the power drain of the system under actual field conditions. This procedure was originally followed. However, when the station was removed from the snow pack (day 5 of testing), a battery charger was attached to the batteries and a second charger which is an integral part of the Hydro-Met system was also connected to "line power." The system operated in this condition for a period of approximately 2-1/2 weeks.

When it was learned that the system was operating on line power, the Watershed technician was instructed to remove the chargers from the system. In doing so, a short circuit was made and a 28-volt current was placed across the 12-volt system. This caused serious damage to the Hydro-Met portion of the system, but the meteor burst portion was unaffected. With the Hydro-Met sensors not operative, the meteor burst message would not get updated and an indicated error was included in the transmitted message. Thus it was not possible to obtain the data necessary to perform an analysis on the power consumption of the unit. However, as will be seen later, the station did provide more information than was originally anticipated.

In addition to these two remote stations which were operated as "permanent" installations, a portable communication unit (PCU) was operated from a number of locations for short time periods. Here, the object of the testing was to determine both the difference in communication rates between the summer and winter periods and the communication rate from sites which were potentially different from those used in the summer test program. The PCU was tested from Dietrich Camp and Prudhoe Bay which were stations used during the summer program and also from McGrath, Bethel, and Kotzebue. At each site the unit was installed and operated for a period of from 4 to 18 hours depending on travel arrangements. Both the fixed message generator consisting of eight 4-digit words and the 16 alphanumeric keyboard input were used at all locations. Figure 3 shows the geographic location of these various test sites.

The PCU was also used as the remote transceiver for interfacing to the AMOS located at the Big Delta Flight Service Station. Under normal operations, the AMOS is interrogated once an hour through a Service A teletype link. During the two days of testing with the MBCS, the AMOS was removed from the Service A link, and updated on a manual basis. The updated message was then transmitted via the meteor burst to the base station in Anchorage. A hard copy of the AMOS output was also provided on a local teletype circuit at the Big Delta Flight Service Station, FAA.

During the first day of testing from the AMOS interface system, a standard dipole antenna (approximately 10 feet long) was used. On the second day of

Figure 2 Revised location of the Environmental Station.

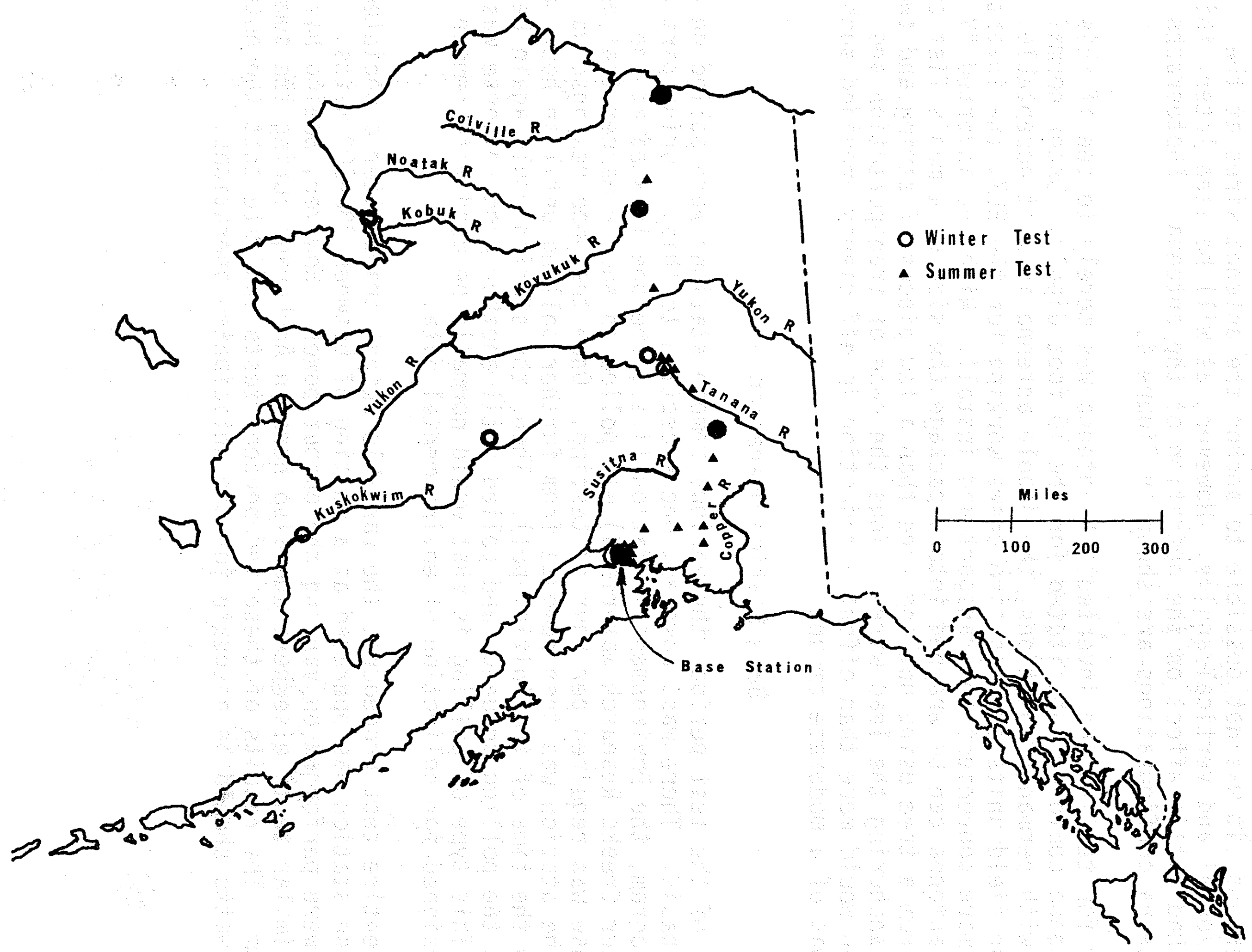


Figure 3 Location of remote units used in the Test Programs.

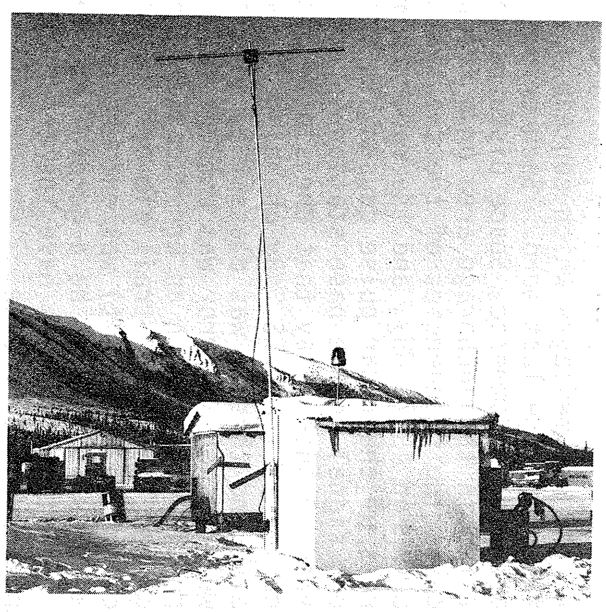
testing, the dipole antenna was replaced with an inverted "V" antenna. The inverted "V" antenna consists of a balum unit placed between two pieces of wire, each approximately 5 feet long. The balum unit is placed on a mast and the two wires anchored in such a way that they form a horizontal angle at the vertex of 45° and are inclined at 45° to the horizon. Due to the temporary nature of the installation, the lack of proper supports, and the occurrence of frozen ground, it was not possible to anchor the antenna wires at the proper horizontal and vertical angles. However, as will be seen later, this apparently had little effect on the operation of the antenna. Photographs of the two antenna configurations are shown in Figure 4.

The purpose for testing the inverted "V" antenna was merely to see if this type of antenna could be substituted for the 10 foot dipole. Under normal operations with permanent stations, the dipole antenna is most acceptable. However, for field units such as fire crews working for the BLM, the inverted "V" is far more convenient to transport and install. With the inverted "V" the entire antenna can be wrapped into a package the size of a man's fist and installed from a tree using nothing more than a few pieces of string and two stakes for anchoring the lead wires. Thus the ease of transportation and installation would more than offset a reduction in efficiency provided such reduction was of a moderate amount.

Base Station Operation

During most of the test period, the various remote stations were polled on a continuous basis. There was, however, one exception to this. During part of the test program, the Environmental Station (i.e., the one located at the Caribou-Poker Creeks Research Watershed) was polled in such a manner that one good response was required per hour of testing. Once the good response was received, the station was then removed from further polling until an hour had lapsed from the time of the initial poll. Then, the station would again be included in the polling sequence and polled until another good response was received. This type of polling is what would normally be used with remote stations designed for collection of environmental data.

During the entire test procedure, the variable output transmitter associated with the base station was operated at a setting of between 800-900 watts. No studies were performed on varying the output power. However, Boeing has performed similar tests elsewhere and also here in Anchorage during the summer test program. The results of these independent tests indicate that the output of 800-900 watts should be adequate for the anticipated operations.



Dipole

Inverted "V"

Figure 4 Antennas used with remote units.

DATA PROCESSING

The output from the test system was through a Model 33 Teletype with the only output being a hard copy teletype printout. With nearly 40,000 messages received at the base station during the 30-day test period, it was necessary to manually reduce the data into a computer compatible format for processing and analysis.

In Figure 5 a typical section of the original output is shown. Here, it can be seen that the Fairbanks Station (31) and the PCU both had the capability of transmitting a fixed character message. With such messages, the form of the message and not the message itself is of primary importance. Thus, in the data processing a coding system was devised such that each message was assigned a code which placed it in a given category. If the message was good it was assigned a code of 1. Under normal operations such messages are the only ones that would be processed by the mini-computer associated with the base station. These messages can be identified in Figure 5 as those which do not have an asterisk (*) following the message.

The bad messages (those followed by an asterisk) were subdivided into three categories each readily distinguishable by its characteristic format. The first classification of bad messages are those caused by meteor trail die-off. With such messages, the first portion of the message is good, and then at some point the signal becomes weak and the message becomes scrambled. Such messages were given a code of 2. This classification is the normal type of "bad message."

The second of these categories are the bad messages which contain a single bit error in one of the data words other than the last word. Such errors were presumed to be caused by the Department of Commerce, Space Disturbance Monitoring Station's radar which is operated in the Anchorage area on a frequency of 49.6 MH_Z. The closeness of the operating frequencies of the two systems (MBCS - transmits on 46.6 MH_Z, receives on 49.73 MH_Z, and the radar transceives on 49.6 MH_Z) coupled with the sharpness of the radar pulse caused its transmission spectrum to spread, giving a strong signal in the base station's receive band. At times, the two systems interfered in such a way that the single bit errors were recorded in the messages received by the MBCS. By changing frequency, this type of error can be eliminated and thus it was classified as a separate category using a code 3. If, however, such an error was encountered in the last word of the message, it is possible that such an error could be either a radar error or an error resulting from the meteor trail die-off. Thus, if such an error (i.e., single bit change in one digit) was encountered in the last word of a message, the message was assumed to be a general bad message and was given a code of 2. Such a distinction does have the tendency to make the classification slightly on the conservative side.

The last type of bad message is one that is typical of operations in the northern latitudes, yet according to Boeing, is uncommon for operations at lower latitudes. In Figure 5 it can be seen that some of the messages have a

```
Time  Sta.                          Message
      ID

Ø132  31 7777   7777   7777   7777   2222   2262   2222   *R
Ø132  31 7777   7777   7777   7777   2222   2222   2222
Ø133  31 7777   7777   7777   7777   2222   2222   2222
Ø133  31 ?688?  8848?  888<?  27;4?  8329?  3>=2?  <5:9?  *
Ø133  31 7777   7777   6777   7777   2222?  2223   2223   *
Ø133  31 7777   7777   7777   7777   2222   2222   2222
Ø134  31 7777   7777   7777   7777   2222   2222   2222
Ø135  31 7777   7777   7777   7777   2222   2222   2222
Ø136  31 7777   7777   7777   7777   2222   2222   2222   *R
Ø136  31 7777   7777   7777?  7767   2222   2222   Ø<1>?  *
Ø137  31 7777   7777   7777   7777   2222   2222   2222
Ø137  31 7777   7777   7777   7777   2222   2222   2222   *R
Ø137  31 7777   7777   7777   7777   2222   2222   2222
Ø138  31 7777   7777   7777   7777   2222   2222   2222
Ø14Ø  31 7777   7777   7777   7777   2222   2222   22Ø:   *
Ø141  31 9888?  8Ø8<?  8888?  8Ø88   =7<=?  <=95?  57?=?  *
Ø142  31 7777   7777   7777   7777   2222   2222   2222
Ø143  31 7777   7777   7777   777?   ====?  ====?  3492   *
Ø144  31 7777   7;Ø4   ?777   7?77   2222?  Ø22=?  :4?Ø   *
Ø146  31 7777   7?>?   ?74<?  8ØØ;   ====?  ====?  =322   *
Ø146  31 ;?;;   77;8?  Ø777?  5>27   >===?  ====?  ==?=?  *
Ø146  31 77?7   7777   7:88?  Ø575   ==;=   222<?  1322   *
Ø146  31 7718   8888?  Ø888?  888<   :323   4Ø<9   2:;;   *
Ø147  31 Ø11??  1166   777>?  7777   2>;;   22>4?  5226?  *
Ø147  31 7777   988>?  77?6   7177   222<?  26Ø2   2::<?  *
Ø147  31 7779?  8888?  888Ø   7?9?   =322   5:3Ø   >9==?  *
Ø147  31 7767?  8886   7?86   38>6   22Ø2   :===?  =9==?  *
Ø147  31 7319?  8888?  8887   7337   32>=   42:3   <16;?  *
Ø147  31 7588?  8888?  8Ø17   7777   2226   2222   2222   *
Ø147  31 7776   7774?  4<44?  4444   =?<4   Ø121   >>>6   *

Ø147  321* 3567  31Ø4←  21Ø6←  17Ø2  411  441  421  3467←  ØØØØ8*
Ø147  31 7798?  4;8Ø   7777   7777   24<=?  3222   2222   *
Ø147  31 7777   75Ø6   7778?  Ø777   22<;?  :5?5   <522   *
Ø147  315 >22Ø?  ?>1=   >>?>   >>>6   444:?  444:?  4442?  *
Ø147  31 8888?  <677   ?777   7777   >>==?  3>==?  ====?  *
Ø147  31 777Ø?  8888?  8678   8888   ====?  ====?  ?322   *
Ø147  31 7?86   >677   7?88?  8888   ====?  ==32   ::>=?  *
Ø147  31 777??  8>77   7777   7779   ===3   22:=?  ====?  *
Ø147  31 7777   7777   7777   7788   ====   2324?  2222   *
```

Figure 5 Typical section of base station teletype printout, i.e. raw data.

format which in no way resembles the fixed message format associated with the good messages of code 1. Such messages are the result of a multipath communication occurring during aurora events. Such messages were given a classification of 4.

During the aurora periods it was possible that so many messages could be received by the base station that the buffer capacity of the mini-computer was exceeded. Under such circumstances the individual messages were lost and a buffer or computer overflow was indicated in the output. During such circumstances a data entry of code 7 "Computer Overflow" was used.

In addition to the message codes, two operational codes were used in processing the data. These included a code 5 for off times and a code 6 for dummy messages. The "Dummy" resulted from the specific input format that was used and was not processed in any of the analyses.

Utilizing the above coding system and the time of each message as indicated by the base station printout, the remote station ID and the date, each message could be classified into a computer compatible format. Once the grouping was performed on a station and date basis, the individual messages were entered as a 5 digit word - the first 2 digits representing the hour, the next 2 digits the minute, and the last digit the code representing the form of the message. For example, a good message (code 1) received at 10:15 a.m. was recorded as 10151.

The messages from the Environmental Station and the AMOS were actual real-time messages where the data itself had meaning. Thus here the actual message, as well as the time and code, were recorded and processed in the analysis. However, a slightly different coding was used. Good messages were still recorded as a code 1, and off times were recorded as a code 5. All bad messages, whether from meteor trail die-off, radar, or aurora were classified as a code 2 "Bad Message." The individual minutes during which computer overflows were recorded were also given a code 2 yet the message entry was recorded as "Computer Overflow."

With the Environmental Station, two cases were found where the message contained an error yet the base station computer did not detect a parity error in the received message and thus the message was labeled by the base station as a "good message." Both of these messages were classified in the data processing scheme as a code 3 and are indicated in the output summaries with an "E" where the error was detected.

The messages from the Environmental Station had a number of parity checks built into the system which were outputted on the teletype when parity errors were detected. An asterisk (*) following the station ID indicates meteor burst parity, a vertical arrow (↑) following the station ID indicates vertical parity in the message, and a horizontal arrow (←) following any of the individual data words indicates horizontal parity in that particular word. A modified system was used to enter these same indicators into the data processing scheme. Here, an asterisk (*) was used for indicating horizontal parity and is printed out with each bad message in the data summaries. Since the occurrence of only meteor burst or only vertical parity was extremely rare, no distinction in the output format was made for such errors. They have, however, been indicated in the initial input data and can be identified if someone should so desire. The occurrence of meteor burst parity and/or vertical parity is indicated in the output summary as a bad message. Figure 6 shows a typical message with parity errors as recorded by the base station teletype.

Once the raw data had been reduced to a computer compatible format and checked for accuracy, a preliminary analysis was performed on a station by station basis. Since the occurrence of a suitable meteor trail capable of providing a communication link between the base station and any given remote station is a random event influenced in part by the time of day, season of the year, distance between the base and remote stations, and the system parameters such as antenna design and orientation, base station output, etc., it becomes necessary to perform a statistical analysis of the data and from this analysis infer what can be expected within the laws of probability concerning the operation of an actual operational system. In its analyses of the data, Boeing Corporation has chosen to use the number of good messages per hour as the controlling statistic. However, it is possible and actually quite common to find a number of meteors grouped together such that there will be a number of good communications in a very short time interval separated by a much longer period when there are no communications. Thus, in the analyses presented here, the primary statistic used in the comparison is the waiting time between consecutive messages. If the analysis were performed on only good messages, then the waiting time would be the time between consecutive good messages. If the analysis were performed on good + radar messages (Note: If the frequency had been changed, the radar messages would have been good messages.) then the waiting time would be the time between consecutive good messages, or good and radar messages, and so on.

Analyses of the distribution of waiting times were made for each station, grouping the data on an hourly basis. Thus, for any station there is a preliminary analysis of the waiting times for the first hour of the first day, then the second hour of the first day, and so on throughout the entire test period. An example of one such output is shown in Figure 7.

During certain test periods, waiting times in excess of one hour were encountered. Such cases involve a somewhat different situation and may cause misinterpretation in the analysis. Consider the case when a good message is received at 0140 and the next good message is received at 0255. The waiting time between consecutive good messages is 75 minutes and was recorded as occurring in hour 3 of the day (between 2 and 3 a.m.) which corresponds to the time grouping of the latter message. Thus, it is possible to have waiting times in excess of 60 minutes recorded for any given hour. Because of computer limitations, a maximum waiting time used in the analysis was set at 119 minutes or 1 hour and 59 minutes. If the waiting time exceeded this limiting value, it was printed out with the preliminary analysis but was not included in the computations on the distribution of waiting times.

The base station was designed to print out the time of each message, but only to the minute. Thus, it is possible to have two or more messages with the same indicated time. For such cases, a waiting time of zero was used in the analysis. Also, for all other possible waiting times, integer numbers (or full minutes) were used as it was not possible to determine the fractional portion of a minute.

Good Message

0019	376
STATUS	000000
TEMP IN	-00008
TEMP OUT	-00006
BATTERY1	01358
BATTERY2	03925
TXCOUNT	01705

Bad Message

0019	376*↑
STATUS	←
TEMP IN	00087
TEMP OUT	00085
BATTERY1	00890←
BATTERY2	02408
TXCOUNT	00932

* Meteor Burst Parity

↑ Vertical Parity

← Horizontal Parity

Figure 6 Examples of Environmental Station data showing good message and bad message with various types of parity as indicated by the base station monitor.

FAIRBANKS STATION

DAY 14 HOUR 23 TO 24

NUMBER OF GOOD MESSAGES = 14
NUMBER OF BAD MESSAGES = 11
NUMBER OF RADAR MESSAGES = 5
NUMBER OF AURORA MESSAGES = 6
NUMBER OF MINUTES WITH COMPUTER OVERFLOW = 0
TOTAL NUMBER OF MESSAGES RECEIVED EXCLUDING PERIODS WITH COMPUTER OVERFLOW = 36.

RATIO BETWEEN GOOD/TOTAL NUMBER OF MESSAGES RECEIVED = 14/ 36 = 38.88 PER CENT

RATIO BETWEEN GOOD + RADAR/TOTAL NUMBER OF MESSAGES RECEIVED = 19./ 36. = 52.77 PER CENT

DISTRIBUTION OF WAITING TIMES FOR GOOD MESSAGES

WAITING TIMES IN MINUTES	0	1	2	3	4	5	6	7	8	9	10	11	12
NO. MESS.	2	3	1	3	1	0	0	1	1	0	0	1	1
PER CENT DIST.	14.2	21.4	7.1	21.4	7.1	0.0	0.0	7.1	7.1	0.0	0.0	7.1	7.1
CUM. PER CENT	14.2	35.7	42.8	64.2	71.4	71.4	71.4	78.5	85.7	85.7	85.7	92.8	99.9

MEAN WAITING TIME = 4.0 MINUTES STANDARD DEVIATION = 3.96

DISTRIBUTION OF WAITING TIMES FOR GOOD + RADAR MESSAGES

WAITING TIMES IN MINUTES	0	1	2	3	4	5	6	7	8	9
NO. MESS.	3	4	2	4	1	2	1	1	0	1
PER CENT DIST.	15.7	21.0	10.5	21.0	5.2	10.5	5.2	5.2	0.0	5.2
CUM. PER CENT	15.7	36.8	47.3	68.4	73.6	84.2	89.4	94.7	94.7	99.9

MEAN WAITING TIME = 2.9 MINUTES STANDARD DEVIATION = 2.52

DISTRIBUTION OF WAITING TIMES FOR ALL MESSAGES

WAITING TIMES IN MINUTES	0	1	2	3	4	5	6	7
NO. MESS.	12	8	9	3	1	0	1	2
PER CENT DIST.	33.3	22.2	25.0	8.3	2.7	0.0	2.7	5.5
CUM. PER CENT	33.3	55.5	80.5	88.8	91.6	91.6	94.4	99.9

MEAN WAITING TIME = 1.6 MINUTES STANDARD DEVIATION = 1.88

Figure 7 Example of computer output for the first step in the analytical procedure used with the Fairbanks data.

Following the individual hourly analysis for each station, an analysis of variance was performed on the data for each hourly grouping. Here, the between group variance was compared to the within group variance in testing the null hypothesis - there is no difference between the means of the two groups. If at some specified confidence level the null hypothesis has to be accepted, then it can be inferred that the two groups are samples from the same population and that there is no apparent difference between the two. If, however, at the specified confidence level the null hypothesis can not be accepted, then it must be interpreted that there is a difference between the two samples and that they are not from the same population. Examples of such comparisons included: a) a comparing of the waiting times for the first hour of the first day for station 1 with the 15th hour of the day for day one and station 1; b) comparing the waiting times for the first hour of the first day for station 1 with the first hour of the last day for station 1; c) comparing the first hour of the first day for station 1 with the first hour of the first day for station 2; and so on. If the null hypothesis is accepted on the first example test, then there is no apparent diurnal variation. If it is accepted on the second example test, then there is no apparent seasonal variation. And if it is accepted on the third example test, then there is no apparent difference between stations. If, in this last example, the stations are at different distances from the base station, and the null hypothesis was accepted, then it can be further concluded that there is no apparent distance effect. This comparative process was performed for all possible combinations.

For someone unfamiliar with statistical analyses, the above may be sometimes confusing and misinterpreted. When the test is made and the null hypothesis accepted, it can be inferred that at a given confidence level it may be stated that there is no apparent difference between the two sample means. Such a condition may result from the two samples actually being from the same population, i.e., there is no difference, or it may result from the spread of the data within either or both groups being so great that the within group variance masks the between group variance to such a point that the between group variance is no longer recognizable. In such a case the two samples may actually be different yet the spread of the data is so great that the difference can not be satisfactorily identified. If the sample means are normally distributed, the probability of saying there is no difference when there actually is a difference is given by: 1 - confidence level. If a confidence level of 95% is used, then on the average, 5% of the time one would conclude that there is no difference between the groups when in actuality there is.

The purpose for making the various comparisons between hourly groups of data was a means of determining where the predominant differences occurred as well as a means of reducing the overall number of data samples. Consider for a moment a hypothetical case in which there were 5 stations, each operating 24 hours a day for 30 days. Presuming that there is a diurnal effect, a seasonal effect, and a station effect, then one would be forced to look at 3600 data groups (24/day for 30 days for 5 stations). If each hourly group contained an average of 20 messages/hour then the statistics for each of the individual 3600 groups would be rather weak. If, however, no difference can be recognized between the individual hourly groups for the various days, then the hourly groups for the 30 days can be treated as one sample and the number of samples is thus reduced by a factor of 30 to 120 samples each having an average of 600 data entries per group. If there is no apparent diurnal variation as well as no seasonal variation then the number of samples is reduced to 5, one for each station, having an average number of 14,400 data entries per group. Note the statistics associated with an analysis of this size sample are far more reliable than those performed on a sample size of 20. To go one step further, if it can also be shown that there is no apparent difference between stations, then the entire record of 72,000 messages could be analyzed as one overall group having one mean value and one set of statistics.

Once the various analyses of variance were performed and the various data groupings performed, each resulting group was analyzed using the original data inputs.

In addition to the above mentioned analyses on the waiting times between consecutive messages, analyses were also performed on the distribution of the various types of messages, (i.e., percentage of good, bad, radar, and aurora), and how these percentages change with the time of day and the season or day of testing. By using the data from the Environmental Station it was also possible to determine the percentage of messages received compared to the number sent by the remote unit. Such comparisons become extremely important in designing power sources for battery operated units. The Environmental Station also provided information on the operating characteristics of the equipment during conditions of extreme cold.

ANALYSIS OF THE DATA

Fairbanks Station

The data from the Fairbanks Station was processed as described above. When an analysis of variance was performed on the consecutive hourly periods for any given day, it was found that in almost all cases the null hypothesis was accepted (95% confidence level), that is, there was no significant difference. Yet, when the data from the early morning hours were compared to the late morning, the afternoon, or the evening hourly data, there was a distinct difference. Thus, it was concluded that the hourly time period was a reasonable grouping for the data and all subsequent analyses were performed on this basis.

The hourly data for each day was then compared on a daily basis. Here, the comparisons showed that there was no significant difference between consecutive days of testing. The hourly data was then grouped on a weekly basis and the hourly data for the first week compared with the hourly data from the second, third, and fourth weeks of the test period. The procedure was then repeated for all remaining combinations of comparisons such as the hourly data from the second week to the hourly data from the third week and so on. In almost all cases the null hypothesis had to be accepted at the 95% confidence level and in most cases, the acceptance could be made at the 99% confidence level. Thus, it may be concluded that for the winter test period (February 12 through March 14, 1975) there was no apparent seasonal difference in the data and that the entire data set can be treated as being from one population in regard to seasonal variations.

The acceptance of the null hypothesis concerning the seasonal variation in the data is significant for several reasons. First, the comparisons were made including all of the hourly periods when the base station was in operation. The periods when interference from the aurora was present, the periods when the base station antenna was rotated away from the Fairbanks station for testing from Bethel and McGrath (for the Bethel testing, the antenna was rotated 105°), and all other periods which may have had an adverse influence on the communication rate were included in the comparisons, yet no significant difference could be found when the hourly data were compared on a day to day basis.

The second major conclusion that may be drawn from the acceptance of the null hypothesis concerning the seasonal variations is one that is more of inference than actual fact. Boeing has stated that a seasonal variation in the communication rate exists such that a low period occurs in late January - early February and that the maximum occurs in late July - early August. Furthermore the difference between maximum and minimum communication rates expressed in terms of messages per hour is approximately a 4 to 1 ratio. Using the Boeing figures and the sinusoidal relationship as proposed, it can be seen that by mid-March the communication rate should be 1-1/2 times that which occurred in early February. Since this was not observed, it may be inferred that:
a) the low point of the curve occurred sometime between mid- to late February

and not January-early February as proposed, or b) the relationship for the northern latitudes is more of a step function and not truly a sine curve. However, with the available data, it is not possible to determine the actual relationship. The only conclusion that can be drawn from the data is that there is no apparent seasonal effect in the distribution of waiting times between the beginning and end of the test period. There is, however, a difference between the summer and winter test data.

Since the seasonal effect is nonsignificant for the test period, the hourly data for each day of the test period may be grouped into 24 samples, one for each hour of the day. The distribution of waiting times for each of the 24 hourly periods was then determined. From these distributions it was then possible to determine a number of statistics for each of the hourly groups. Two such statistics are shown in Figure 8. There, the mean waiting time and the 90 percentile (90% of the messages were received in the indicated time or less) are plotted versus the time of day. From these curves it can be seen that the mean waiting time varied between 2.0 minutes for the period between 10-11 a.m., and 7.0 minutes for the period between 5-6 p.m. The numbers listed along the top margin of the curve are the number of messages for each hourly group used in defining the individual frequency distributions from which these statistics were drawn.

In earlier discussions it was noted that the diurnal variation in message rate expressed in terms of messages per hour was approximately a sine curve with the maximum occurring in the early morning and the minimum occurring in the late afternoon or early evening. If mean waiting time is used as the controlling statistic instead of messages per hour, the diurnal relationship should again be a sine curve but with the positions of the maximum and minimum values interchanged. When the data from the summer test program was plotted in such a manner, the expected sinusoidal relationship was obtained. However, from Figure 8 it can be seen that the resulting function for the diurnal variation for the winter test data is not sinusoidal. Furthermore, the occurrence of the daily minimum waiting time occurs in the late morning (9-11 a.m.) and not in the early morning (5-6 a.m.) as had been expected. This change in functional relationship and timing of the minimum waiting time is a result of the increased influence of the auroral periods. When the auroral periods are encountered, the waiting time between consecutive good messages was increased. When the aurora and non-aurora periods are grouped together, they have a moderating effect on each other which tends to increase the mean waiting time and alter the expected functional relationship. Since adverse auroral activity was never encountered during the late morning period, the expected low waiting times were experienced as anticipated.

For each of the individual hourly groups there is a frequency distribution curve which defines the percentage of the messages that were received within a given waiting time or less. Two such curves are shown in Figure 9. There, the frequency distributions for the hour with the minimum mean waiting time and the hour with the maximum mean waiting time are shown. Similar curves exist for the remaining 22 hourly groups. For the hourly period with the minimum mean waiting time it can be seen that 35% of the messages were received with waiting times of less than one minute, 60% were received in one minute or less, and 97.2% were received in 10 minutes or less. Similar figures can be seen for the hour with the largest mean waiting time.

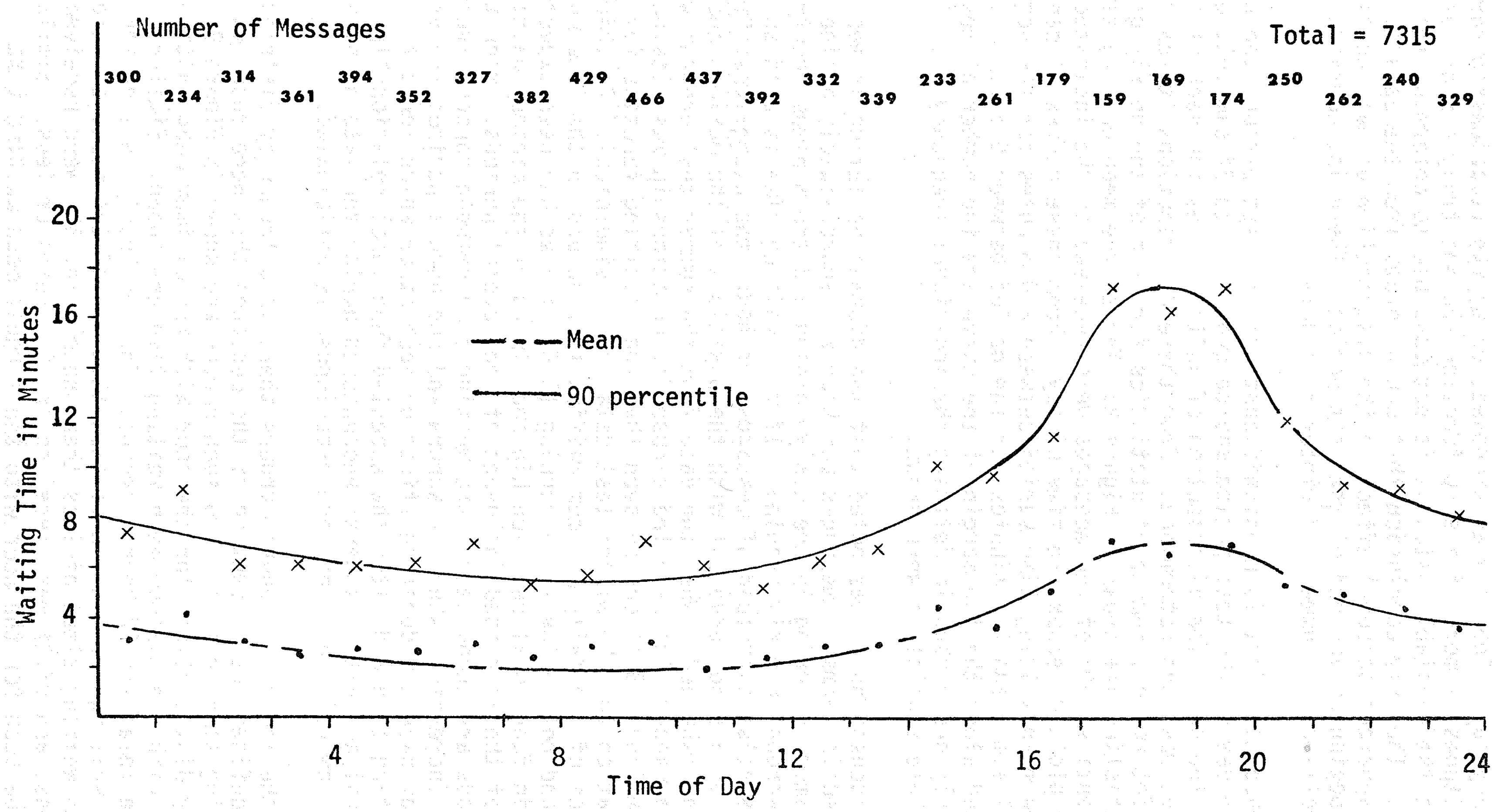


Figure 8 Diurnal variation in waiting times for GOOD messages from Fairbanks station.

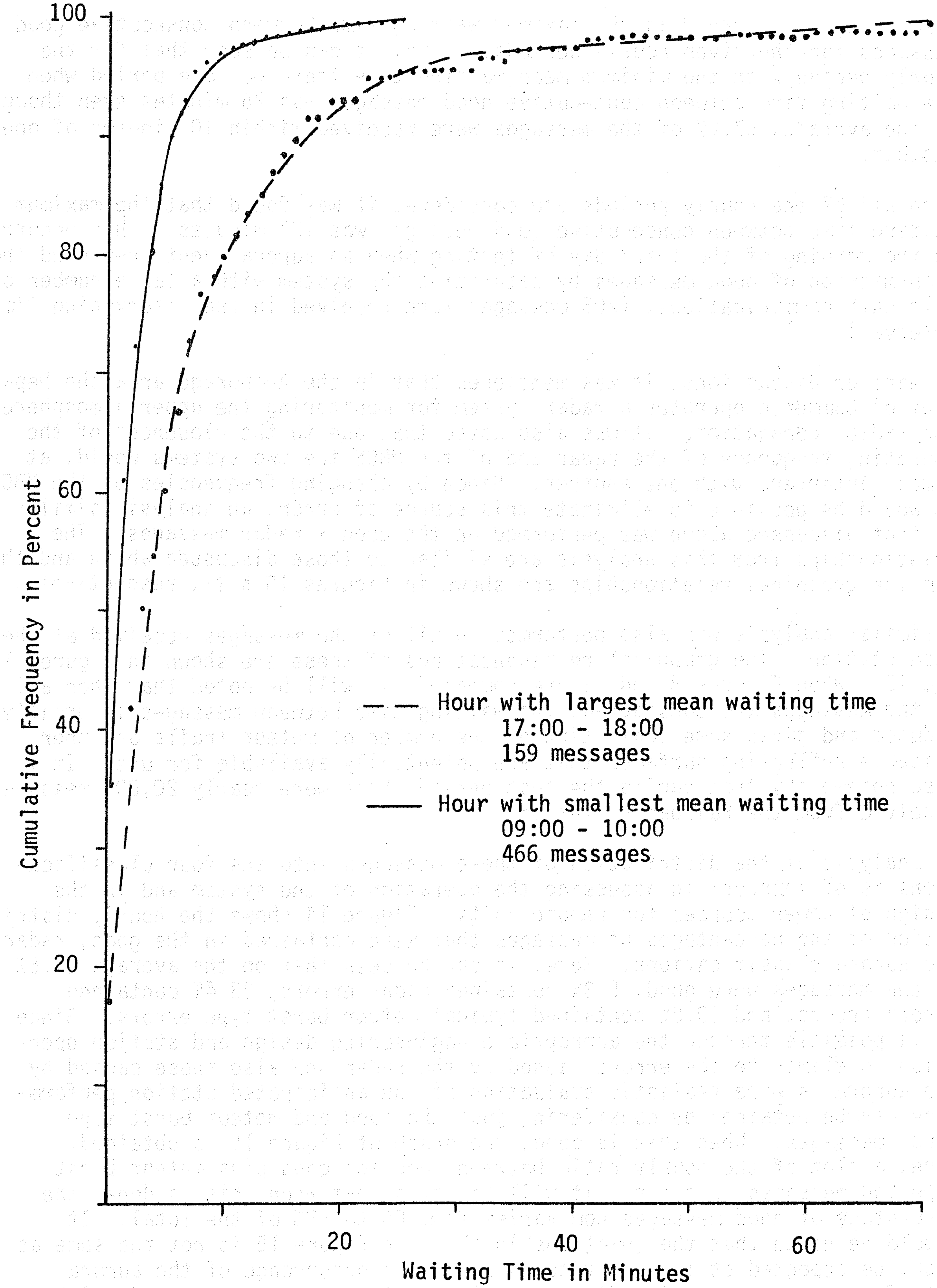


Figure 9 Examples of cumulative frequency distributions for GOOD messages from Fairbanks station.

Also shown in Figure 9 is the maximum waiting time between consecutive good messages for the given hourly periods. Thus, it can be seen that for the hourly period with the minimum mean waiting time there was one period when the waiting time between consecutive good messages was 26 minutes even though, on the average, 97.2% of the messages were received within 10 minutes of one another.

When all of the hourly periods are considered it was found that the maximum waiting time between consecutive good messages was 107 minutes. This occurred on the morning of the third day of testing when an aurora event prevented the transmission of good messages by saturating the system with a large number of multipath communications, (205 messages were received in the intervening time interval).

In earlier discussions, it was mentioned that in the Anchorage area the Department of Commerce operates a radar system for monitoring the upper atmosphere for radio propagation. It was also noted that due to the closeness of the operating frequency of the radar and of the MBCS the two systems would, at times, interfere with one another. Since by changing frequencies of the MBCS it would be possible to eliminate this source of error, an analysis similar to that discussed above was performed on the good + radar messages. The relationships from this analysis are similar to those discussed above and the similar graphical relationships are shown in Figures 10 & 11, respectively.

A similar analysis was also performed on all of the messages received at the base station. The graphical representations of these are shown in Figures 12 and 13. When Figures 8 and 12 are compared, it will be noted that when all of the messages are considered, the waiting time between messages is greatly reduced and gives some indication of the number of meteor trails or other suitable reflecting surfaces that are potentially available for use. It is also noteworthy that during the test period there were nearly 20,000 messages received from the Fairbanks station.

An analysis of the distribution of these messages into the four classifications is of interest in assessing the operation of the system and in the design of power sources for remote units. Figure 14 shows the hourly distribution of the percentages of messages that were contained in the good, radar, and aurora classifications. Here, it can be seen that on the average 41.5% of the messages were good, 5.3% contained radar errors, 33.4% contained aurora errors, and 19.8% contained typical meteor burst type errors. Since it is possible through the appropriate engineering design and station operation to eliminate the errors caused by the radar and also those caused by the aurora, a more realistic evaluation of the anticipated station performance can be obtained by considering just the good and meteor burst type error messages. When this is done, the graph of Figure 15 is obtained. Here, a plot of the hourly ratio between good and good plus meteor burst type bad messages is shown. It will be noted that when this is done, the percentage of good messages now varies from 60 to 82% of the total. It should be noted that the relationship shown in Figure 15 is not the same as might be expected at lower latitudes where the occurrence of the aurora interference is not a significant problem. Since during the non-daylight hours, the occurrence of the aurora reduced the number of good messages, the relationship presented in Figure 15 is unduly biased downward. Also,

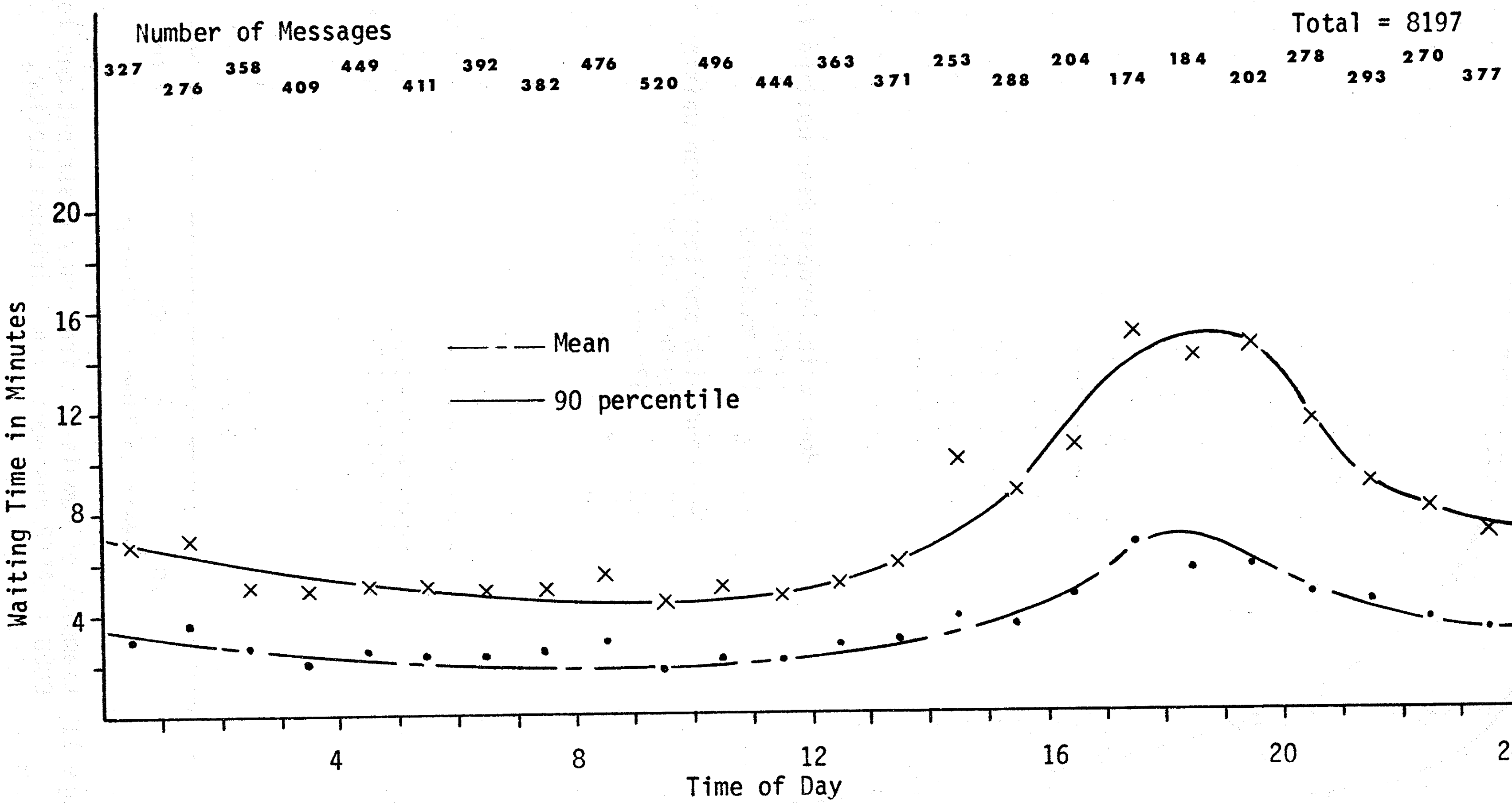


Figure 10 Diurnal variation in waiting times for GOOD + RADAR messages from Fairbanks station.

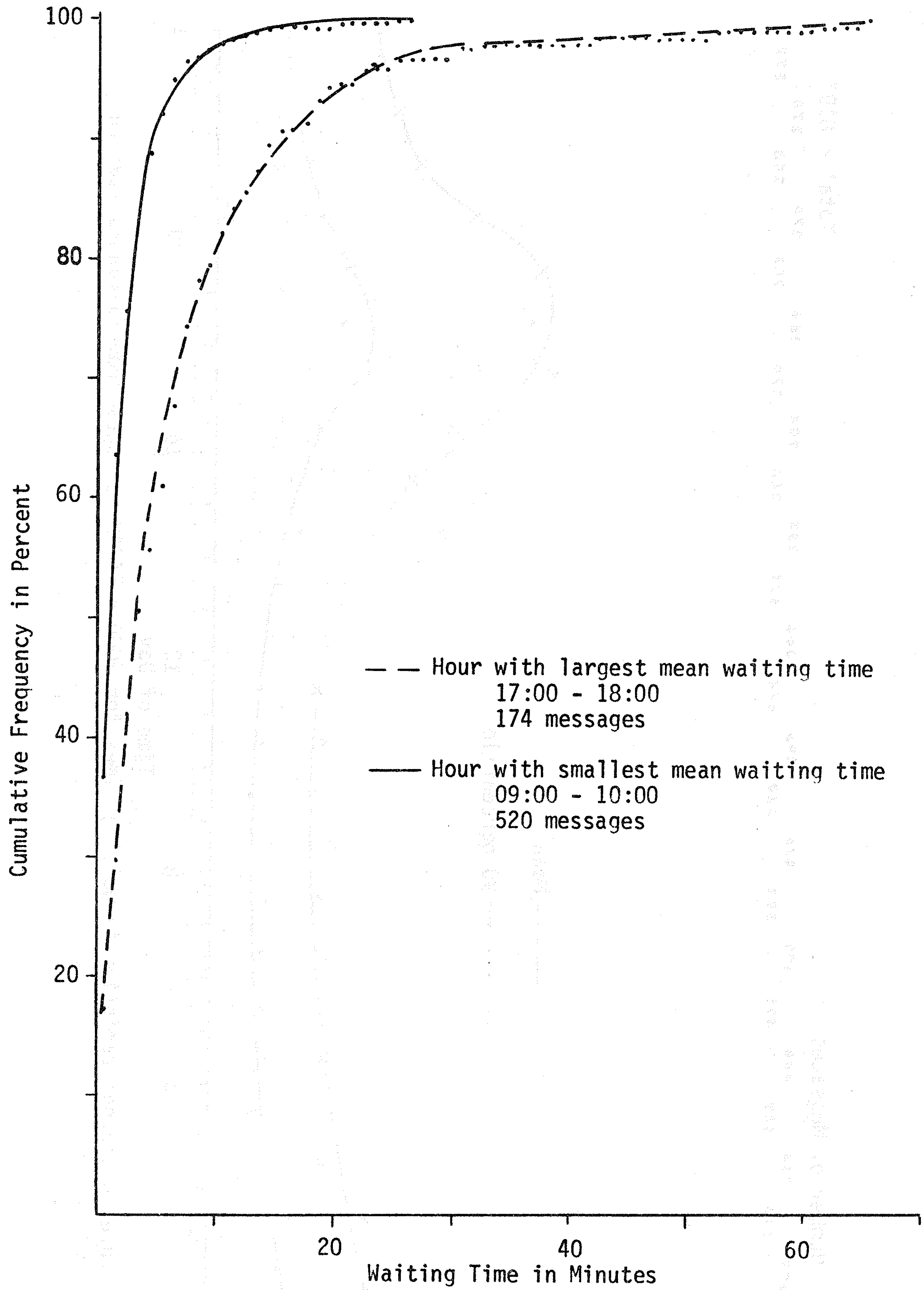


Figure 11 Examples of cumulative frequency distributions for GOOD + RADAR messages from Fairbanks station.

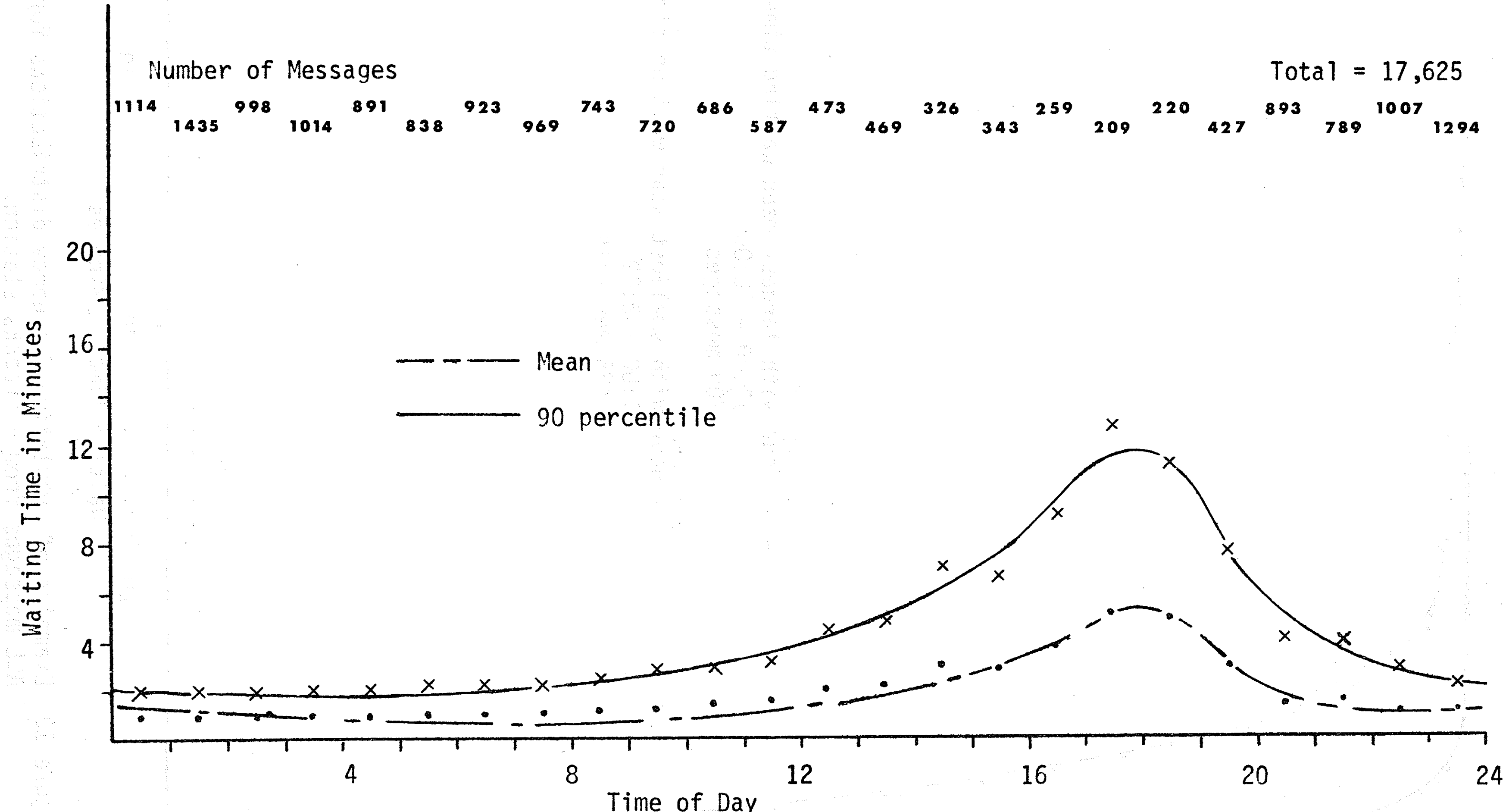


Figure 12 Diurnal variation in waiting times for ALL messages from Fairbanks station.

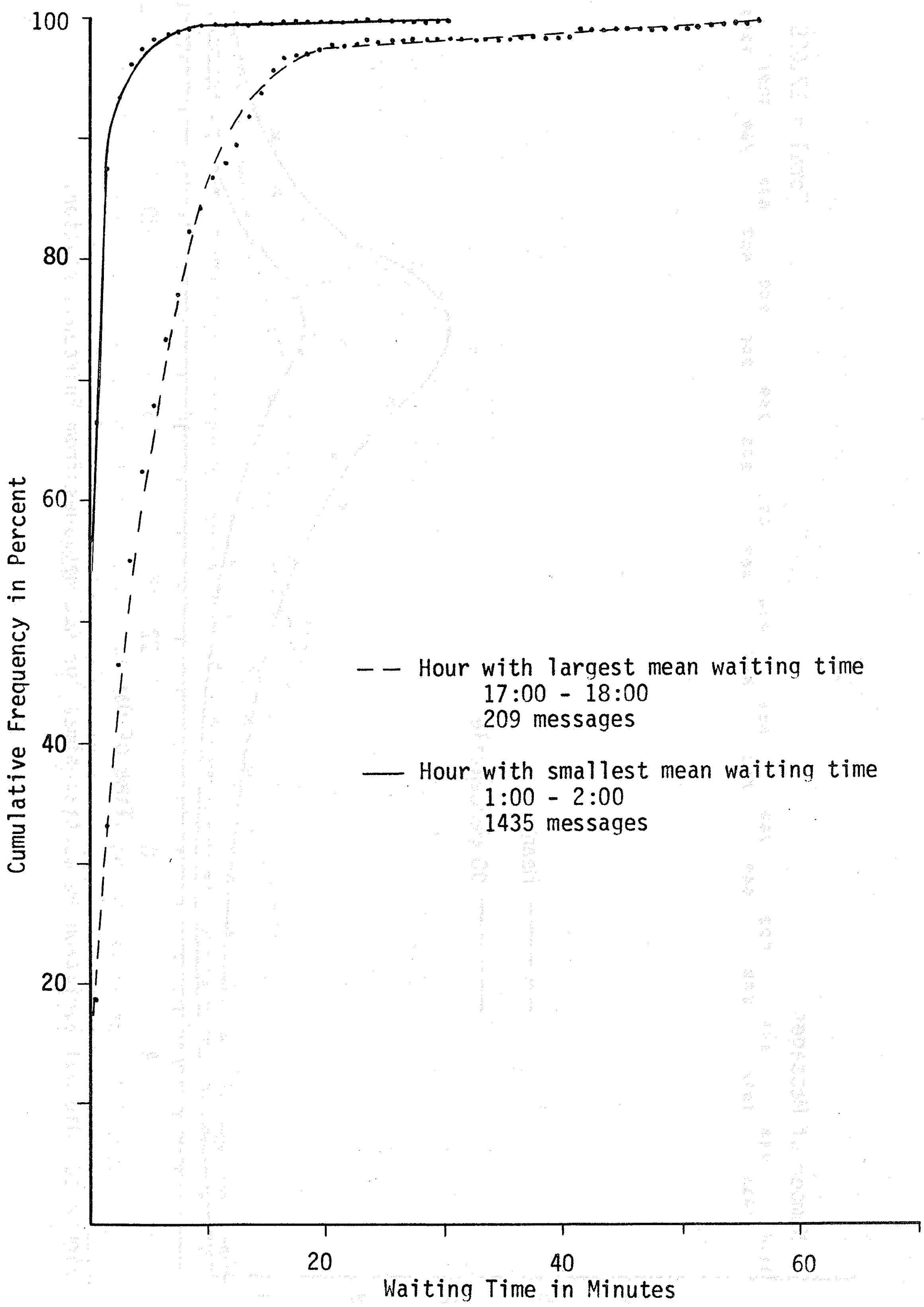


Figure 13 Examples of cumulative frequency distributions for ALL messages from Fairbanks station.

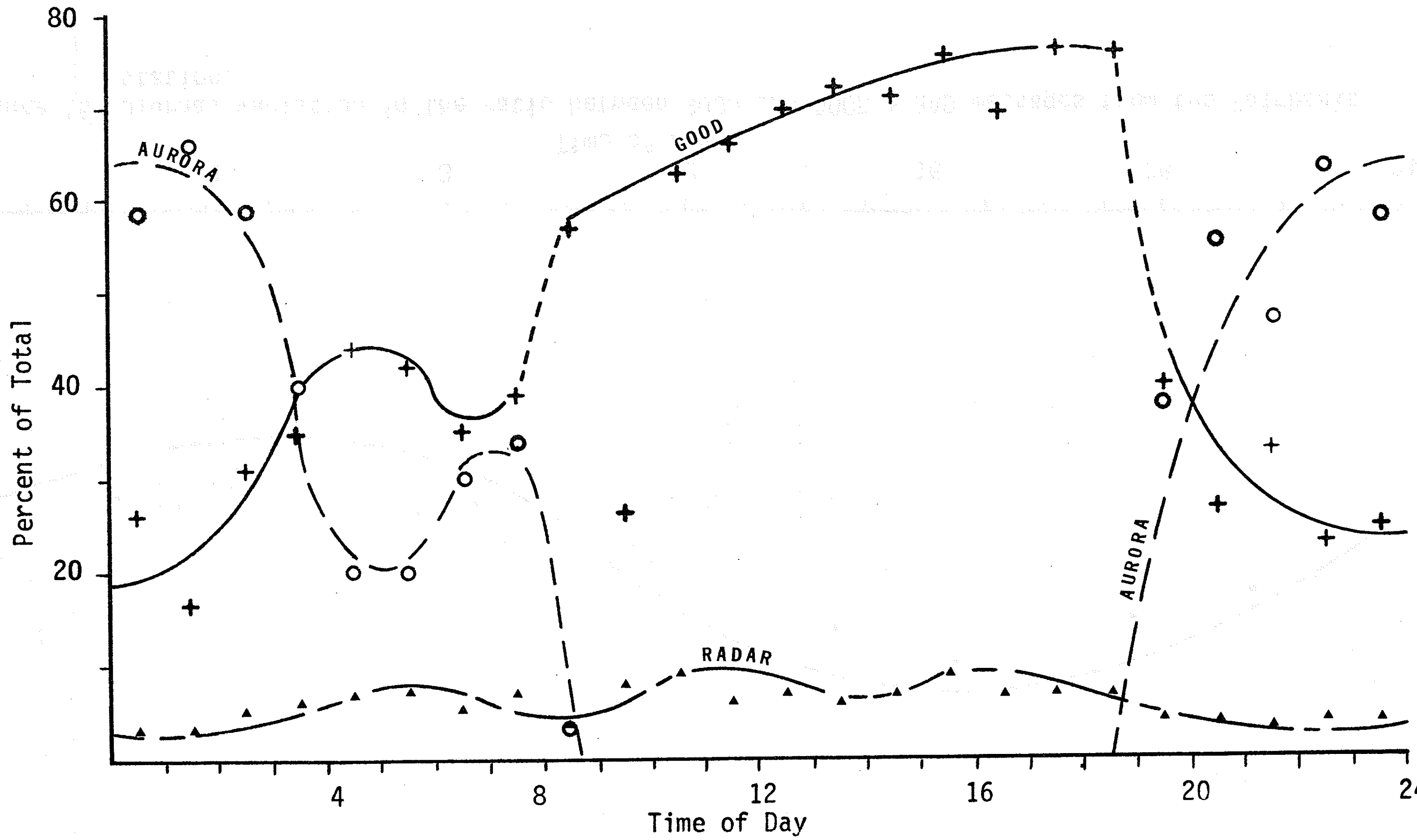


Figure 14 Diurnal variation in the distribution of the various types of messages received from the Fairbanks station. Number of messages: Good 7315 = 41.5%; Radar 927 = 5.3%; Bad 3490 = 19.8%; and Aurora 5893 = 33.4%.

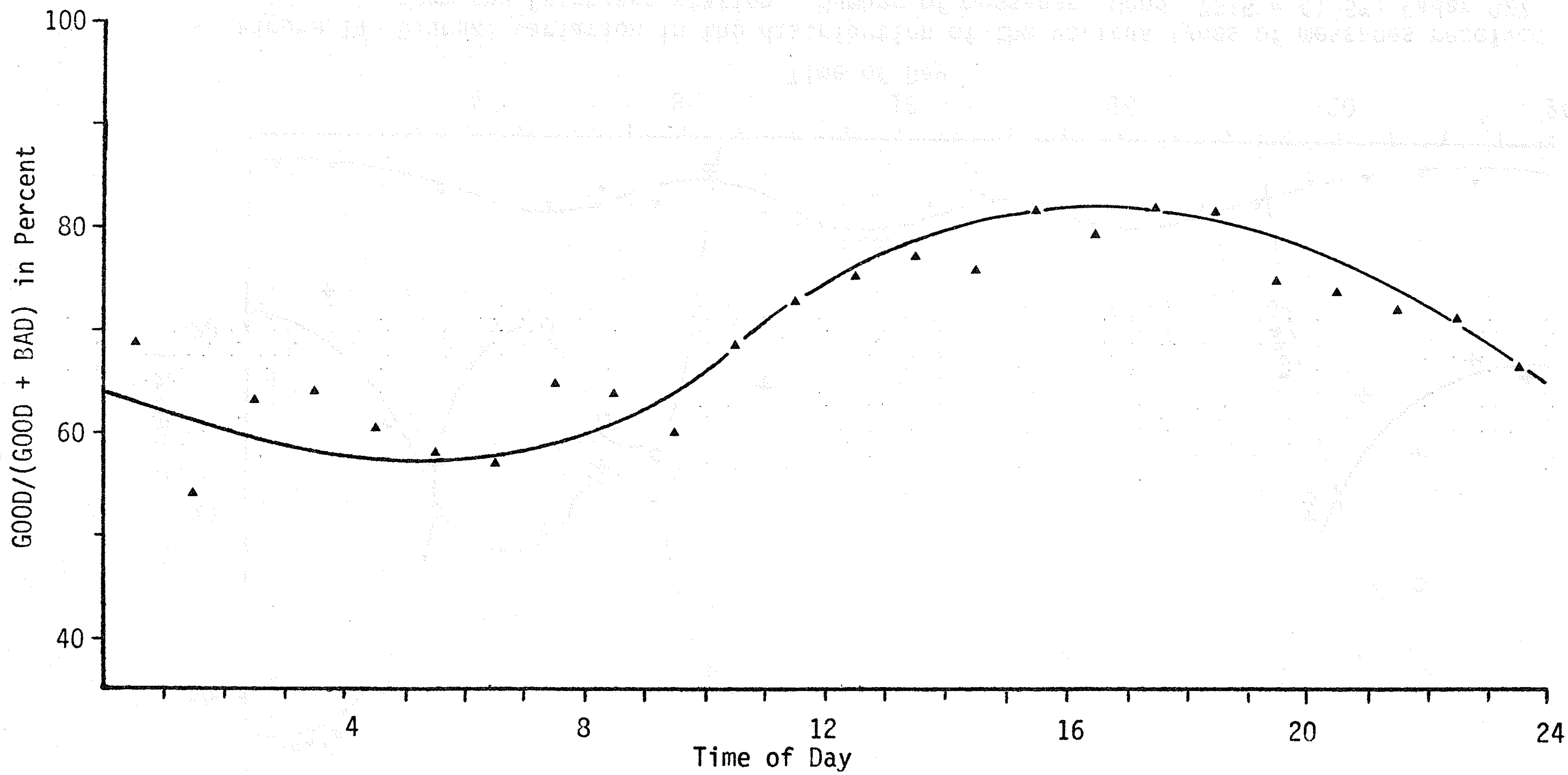


Figure 15 Diurnal variation in the ratio between GOOD and GOOD + BAD messages from the Fairbanks station.

the occurrence of the radar errors is such that a large percentage of these messages would normally be good messages if the radar interference had not been present. Thus, this also tends to bias the entire curve downward. When these additional factors are considered it would appear that under normal operations, 80 to 90% of the messages received at the base station would be good messages.

For an operational system, the base station is normally programmed to process only the good messages. When messages with parity errors (bad messages) are encountered, the system would merely continue to probe the remote station until such time that a good message was received. Therefore, the percentage of good messages is of primary importance in designing the power source for battery operated units and has only minimal effect on the operation of the base station or remote stations operated on line power. Since only the good messages would normally be processed by the base station, the occurrence of bad messages would have no effect on the subsequent processing of the raw data once the message had been accepted by the base station.

Environmental Station

The Environmental Station was operated as a real-time data acquisition site and therefore, several of the analyses performed on the data from the other stations transmitting a fixed message pattern were not possible. Also, the scheduling sequence, or the time when the station was called by the base station, was changed throughout the test period. Thus, it was necessary to use a slightly modified procedure throughout the analysis of these data.

As mentioned earlier, the data were coded into two main categories, good and bad messages. Although the aurora messages were generally distinguishable from the general meteor burst type of bad message, no attempt was made to classify them into a separate category.

During the first 15 days of the test period, the Environmental Station was operated on a continuous probing schedule. For this time period, the same type of analyses was performed on the data as was performed on the data from the Fairbanks Station. However, since the message itself contained actual data, the format of the preliminary output was slightly modified. Figure 16 shows a typical example of one such hourly grouping of the data. The first portion of the printout contains the time of each message (good and bad) plus the actual content of the message. The first word is the status or check on the sensors; the second is the outside temperature in °F; the third is the temperature in °F within the electronics unit; the fourth is the voltage of one of the batteries (times 100 volts); the fifth is the voltage of the other battery (times 100 volts); and the last is the number of times since the beginning of the test period that the transmitter has sent a message. (Note: The TX counter would recycle itself at a value of 2047, and the outputted value is the actual value as sent by the remote station. In comparing data from the beginning to the end of the test period, the number of cycles must be included in the computations.)

The electronics associated with the Hydro-Met interfacing between the sensors and the meteor burst transceiver were set in such a way that an updated

ENVIRONMENTAL STATION - CARIBOU-POKER CREEKS RESEARCH WATERSHED

DATE 2 21 75

TIME	MESSAGE GOOD						BAD					
8 1	0	13	18	1367	3927	41						
8 4	0	13	18	1367	3927	41						
8 5	0	13	18	1367	3927	43						
811							0	13	18	1367	3927	60*
816	0	14	18	1363	3927	45						
816	0	14	18	1363	3927	45						
817	0	14	18	1363	3927	45						
825	0	14	18	1365	3927	48						
827	0	14	18	1367	3927	50						
829	0	14	19	1367	3927	50						
833	0	15	21	1367	3927	52						
834							0	15	21	1367	3935	2046*
835	0	15	21	1367	3927	52						
843	0	16	21	1368	3927	55						
847	0	16	22	1368	3927	57						
856							0	17	22	1368	3904	61
856	0	17	22	1368	3927	58						
857	0	17	22	1368	3927	58						

DAY 10 HOUR 8TO 9

NUMBER OF GOOD MESSAGES = 15
NUMBER OF BAD MESSAGES = 3
TOTAL NUMBER OF MESSAGES RECEIVED EXCLUDING PERIODS WITH COMPUTER OVERFLOW = 18.
NUMBER OF REMOTE TRANSMISSIONS = 20

RATIO BETWEEN GOOD/TOTAL NUMBER OF MESSAGES RECEIVED = 15/ 18 = 83.33 PER CENT

RATIO BETWEEN GOOD/TOTAL NUMBER OF MESSAGES SENT = 15/ 20 = 75.00 PER CENT

RATIO BETWEEN TOTAL NUMBER OF MESSAGES RECEIVED/TOTAL NUMBER OF MESSAGES SENT = 18./ 20 = 90.00

DISTRIBUTION OF WAITING TIMES FOR GOOD MESSAGES

WAITING TIMES IN MINUTES	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
NO. MESS.	1	3	3	1	2	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0
NO. MESS.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
PER CENT DIST.	6.6	20.0	20.0	6.6	13.3	0.0	0.0	0.0	13.3	6.6	0.0	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PER CENT DIST.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6	
CUM. PER CENT	6.6	26.6	46.6	53.3	66.6	66.6	66.6	66.6	79.9	86.6	86.6	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3
CUM. PER CENT	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	99.9	

MEAN WAITING TIME = 6.2 MINUTES STANDARD DEVIATION = 9.41

DISTRIBUTION OF WAITING TIMES FOR ALL MESSAGES

WAITING TIMES IN MINUTES	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
NO. MESS.	2	5	2	1	2	1	1	0	2	1	0	0	0	0	0	0	0	0	0	0
NO. MESS.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
PER CENT DIST.	11.1	27.7	11.1	5.5	11.1	5.5	5.5	0.0	11.1	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PER CENT DIST.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	
CUM. PER CENT	11.1	38.8	50.0	55.5	66.6	72.2	77.7	77.7	88.8	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4
CUM. PER CENT	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4	99.9	

MEAN WAITING TIME = 5.2 MINUTES STANDARD DEVIATION = 8.66

Figure 16 Example of computer output for the first step in the analytical procedure used with the Environmental Station data.

message would be provided to the meteor burst system on a 3 minute interval. With the system interrogating on a continuous basis, it was possible to receive several messages at the base station within the 3 minute time interval between updates. When this occurred, the same message would be recorded for all receptions which occurred during the time between updates. In most cases this caused no problem. However, with the counter on the number of transmissions this operation could cause a misinterpretation of the outputted data in that it was possible to show more indicated receptions than transmissions during any given hourly period. The discrepancy caused by the delay in updating the message would then be applied to the statistics for the next hourly period.

An analysis of variance was performed on the hourly data from the Environmental Station for the period when it was operated on a continuous probe basis. Here, as with the Fairbanks Station, no significant difference could be found between the hourly data from the beginning of the test period and that at the end of the period. Thus it may be inferred that there is no apparent seasonal variation in the data and that they may be treated as one sample.

However, as with the Fairbanks Station, an analysis of variance on a diurnal basis indicated that there was a difference in the hourly data. A graphical representation of this diurnal variation is shown in Figure 17. Also shown in Figure 17 is the diurnal variation of the mean waiting times for the Fairbanks Station for the same time period. It will be noted that the two relationships are not the same. This conclusion is also supported by an analysis of variance using the corresponding hourly data from each station.

The distinct difference between the communication rates from the Environmental Station and the Fairbanks Station, both located at approximately the same distance from the base station and in the same general direction, could presumably be attributed to a number of factors including: a) a difference in site locations; b) the different addressing schemes used on the two stations [the Fairbanks Station used a 5 bit address and the Environmental Station used a 7 bit address]; c) some difference in the internal electronics of the two stations; or d) some unknown factor.

As mentioned earlier, during the third week of testing, the field personnel accidently short circuited the 28 volt power source across the 12 volt electrical system and destroyed much of the electronics associated with the Hydro-Met unit. However, the meteor burst unit was unaffected and continued to operate. With the Hydro-Met inoperative, the communication rate from the Environmental Station measured in messages per hour nearly doubled and at least equalled the rate from the Fairbanks Station. However, with the Hydro-Met unit not operating, it was not possible to readily distinguish good from bad messages. A comparison of the total number of messages received from the Environmental Station with the total number of messages received at the Fairbanks Station indicates that there was no significant difference between the two stations. It should be noted that this comparison was made using only a limited amount of data in comparison to what was used in the other portions of the testing, and thus, the small sample size (3 days data) may have adversely influenced the indicated results. If it is assumed that the small sample was representative of the actual conditions, then it may be concluded that the Hydro-Met unit did interfere with the meteor burst system and that the two research units were not compatible.

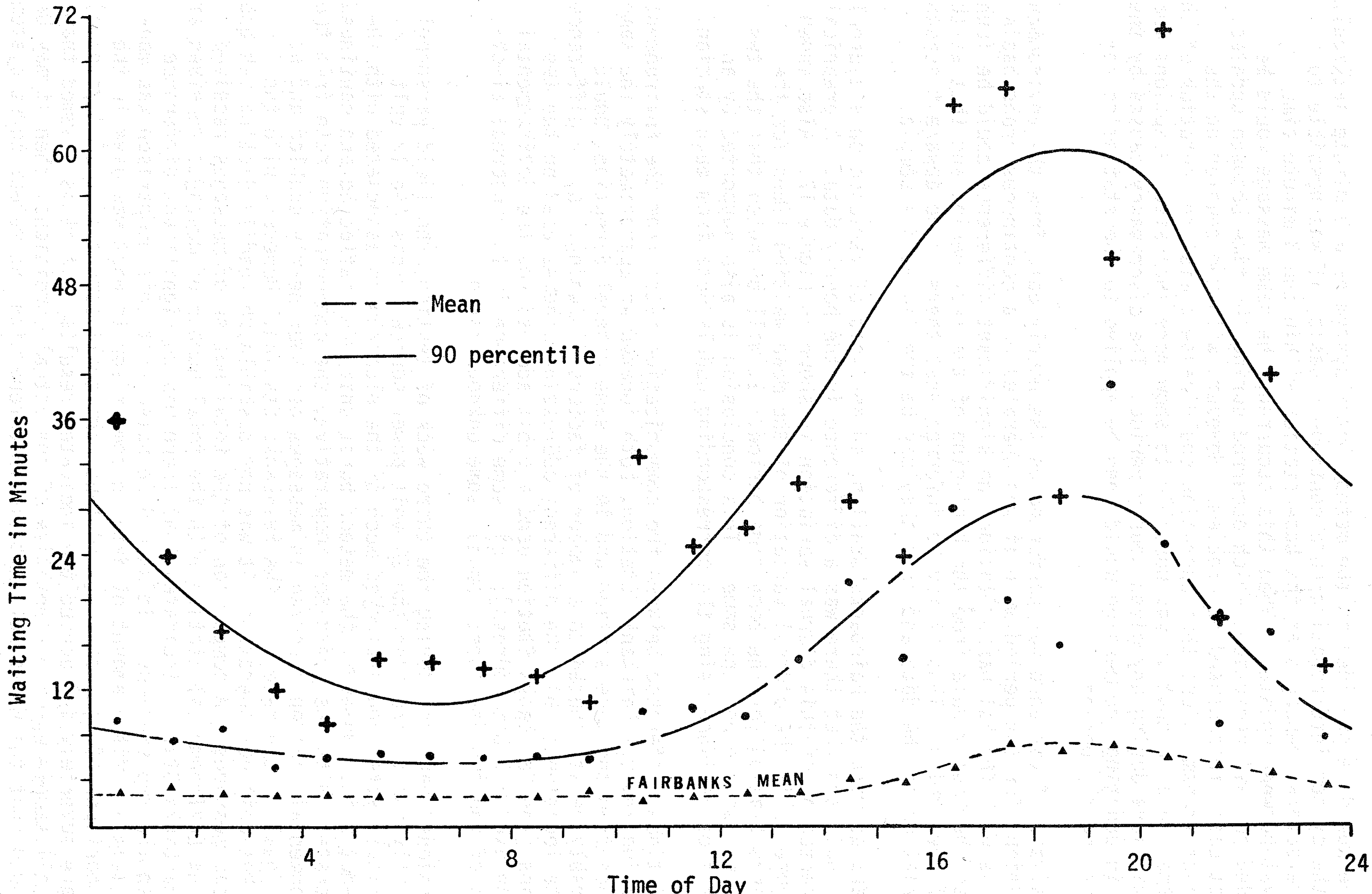


Figure 17 Diurnal variation in waiting times for GOOD messages from Environmental station.
Note: Ordinate scale is half that used in Figures 8, 10, & 12 for the Fairbanks station.

This same conclusion was obtained by the Boeing staff working independently on the analysis of the data. Furthermore, it has been reported that Boeing has subsequently reviewed its design of the Hydro-Met system, located the source of the interference, and made appropriate design changes to exclude subsequent difficulties from occurring in the production model of the equipment.

An analysis of the diurnal distribution of waiting times for the Environmental Station viewed with the knowledge that the Hydro-Met unit was providing a local interference which reduced the sensitivity of the meteor burst system reveals some interesting conclusions. With the interference present, the meteor burst unit was sensitive only to the stronger signals. When a weak signal was received, such as might be obtained from reflection off of a weak meteor trail, the local interference was sufficient to block out the signal. With the Fairbanks Station which did not have the interference, both the weak and strong signals were used for propagating messages. When the data from the Environmental Station is considered, it can be seen that the diurnal variation approximates a sine curve with an amplitude of approximately 4:1, the expected value.

If it is assumed that the above conclusion is correct, and that the data from the Environmental Station is a measure of the strong meteor trail responses, then it must also be concluded that the data from the Fairbanks Station is a combination of the strong meteor trail responses plus some other effect. Here, it is proposed that the data from the Fairbanks Station (plus that from all of the other stations except the Environmental Station) is a representation of the combined effects of the meteor trail propagation via low level aurora activity or other suitable reflecting surfaces which were present throughout the day. If this hypothesis is correct, then the statistics associated with the Environmental Station data and not those of the Fairbanks Station are the set that should be used in predicting what might be expected from an operational system.

The use of the statistics from the Environmental Station and not those from the other stations would be based solely on the assumption that the Environmental Station data are a representation of the meteor burst propagation and that the variability associated with the combined effect noted in the data from the other stations is currently unknown and thus unpredictable. Once a system has been operated for sufficient time that the combined effect as shown in the data from the Fairbanks Station (as well as that from all other stations except the Environmental Station) could be determined, then these new data could be used for further installations.

During the third week of testing, the Environmental Station was operated on a probing sequence whereby the remote station would be probed until such time that a good message was received at the base station. Once a good message was received, the station address was removed from subsequent polling until such time that a predetermined time interval had elapsed from the beginning of the previous polling period. For example, consider a probing sequence which began at 0215, and a good message being received at 0220.

At 0220 the base station would remove the station address from subsequent polls until 0315 at which time it would again probe until a good response was received.

With this type of probing sequence, the waiting time was defined as the interval between the time the base station began polling the specified remote and the time of the response. In the example given above, the waiting time would be 5 minutes or the difference between the time of the message (0220) and the time of the beginning of the polling sequence (0215).

A third type of polling was also used. Here, the base station would poll the remote unit for a preset time interval. If no response was received, the station address was removed from subsequent polling until the cycle was again repeated. Here, an example of the sequence might be: Beginning on the hour, poll for 15 minutes or until such time that a good response is obtained. If no response is obtained within 15 minutes, shut down until the beginning of the next hour at which time the sequence would be repeated. With this type of polling there are two distinct types of waiting times: a) the actual time between the beginning of a polling sequence and the receipt of a message; or b) an unknown time in excess of the polling sequence (in the example - 15 minutes).

It was during this portion of the test program that the short circuiting of the Hydro-Met unit occurred and thus, there was only a four day period during which the two intermittent types of polling were used. With the distinct diurnal variation in the data, it can be seen that there were at most four data entries in each of the hourly data groupings. With this limited number of samples, it was not possible to adequately compare the response under this type of polling with that obtained from the continuous probing portion of the test program. However, it should be noted that in all instances, the waiting times were within the expected range as determined from the continuous polling analysis.

On several occasions, a false response was received at the base station even though the specified address was not included in the polling message. Such conditions could occur either from the radar or other interference causing a bit error in the transmitted station address. When this occurred, the remote unit interpreted the probing signal with the bit(s) error(s) as a correct address and responded accordingly. Thus it would appear that for a large operational system, greater separation between the various remote station addresses should be provided than that which was used on the research unit in this test program.

The occurrence of false responses was noted for both the aurora and non-aurora periods. The aurora periods represent a somewhat special case and are discussed in detail in later portions of this report.

With the Environmental Station, the actual message as well as the data on communication performance were of importance. Here, two factors were of primary significance: a) the operation of the equipment during periods of low temperatures: and b) the number of times that the remote unit was switched from a receive to a transmit mode. During the period that the station was in operation, an indicated low temperature of -23°F was recorded on the base station printouts. However, the NWS standard thermometer located at the site indicated a low temperature of -32°F. Part of the difference between the two readings can be attributed to a 22 hour period during which the base station antenna was rotated away from the Fairbanks area for testing from Bethel and no messages were received from the Environmental Station. However, a spot checking of 15 individual temperature readings as indicated by the Boeing system and the NWS standard thermometer located at the test site indicated that the Boeing system consistently indicated a temperature which was warmer than that indicated on the NWS standard thermometer. This difference ranged from 3 to 7°F with a mean value of 5°F. If this calibration correction is applied to the output data transmitted over the meteor burst system, it can be seen that the system did operate satisfactorily at a temperature of -28°F (-33.3°C). Thus the system did operate at temperatures below the specified limits (outputted and/or calibrated) without any apparent malfunction.

The data from the counter located on the remote transceiver provided much useful information concerning the efficiency of the remote unit. When the data for the period during which the entire system was operative is considered, it was found that the average ratio between the number of messages received and the number of messages sent by the remote unit was approximately 31.6% and is based on nearly 8,300 transmissions from the remote station. These figures include all operating periods including the continuous probing sequence, the periodic probing sequence, and all periods with aurora interference. When the periods of continuous probing and without aurora interference are considered, it was found that the ratio between messages received and messages sent increased to 56.6%. If the comparisons are made on the basis of the number of good messages received to the total number of messages sent, it was found that for all periods of testing, the ratio was approximately 11.2% and for the periods without aurora interference approximately 44.6%.

The significance of the above computations concerning the ratio between the number of messages received at the base station and the number of messages sent by the remote unit is of prime importance in designing the power source for remote units operated on self-contained power sources. When the test data for all time periods are considered it can be seen that it took nearly nine attempts by the remote unit to get one good message through to the base station. When the aurora effects were not present, it took approximately 2.2 attempts to get one good message through to the base station.

When the figures presented above are compared to the previous figures concerning the diurnal variation in the percentage of good messages received at the Fairbanks Station (Figures 14 & 15), it can be seen that there is a difference between the two. With the Fairbanks Station, the comparison is between good and bad messages received and data on the number of transmissions was not available. The comparisons presented above for the Environmental Station are for the number of messages received versus the number of remote transmissions. When the number of messages received from the Environmental Station are subdivided as was done with the data from the Fairbanks Station, it was found that a distribution similar to that shown in Figure 15 was also obtained. Thus, it may be inferred that for the 20,000 messages received from the Fairbanks Station there must have been approximately 180,000 transmissions. This figure does include all operating times including those with auroral interference.

AMOS Interfacing

For a period of approximately 40 hours the portable communication unit (PCU) was interfaced to the NWS AMOS located at the Big Delta Flight Service Station. The station was polled on a continuous basis and operated around the clock. The output messages from the AMOS were processed similar to those from the Environmental Station. The messages were coded into either a good or a bad category and a distribution of waiting times between consecutive messages was then performed. An example of the preliminary output is shown in Figure 18. The time of each message and the actual message content for each good message are shown. In the example both the alphanumeric capabilities of the PCU and the data transmission capabilities are demonstrated. The message "AMOS NOT YET" was transmitted with the PCU in the alphanumeric mode and the subsequent messages such as "AMOS 20/12/3401/M 000" originated with the AMOS and were transmitted in the data mode.

An analysis of variance was performed on the corresponding hourly data from the AMOS and the Fairbanks Station. The results of this comparison indicate that at the 95% confidence level there was no apparent difference between the two samples. Thus it may be concluded that the larger data sample obtained from the Fairbanks Station is representative of what might be expected if the AMOS station had been operated for a similar time period.

Remote Unit Antenna Test

During the testing from the AMOS located at Big Delta, the antenna used on the remote unit was changed from the standard dipole to an inverted "V". The change was made approximately midway in the testing program and each antenna was used for the various portions of the diurnal variation curve. As stated above, when the hourly data from the AMOS station was compared to that from the Fairbanks Station it was found that at the 95% confidence level there was no apparent difference between the two stations. Since half of the test data from the AMOS was received with a dipole antenna and the other half was received on the inverted "V" antenna, it may also be concluded that the different types of antennas used had no apparent effect on the communication rate between the remote and base stations.

Other Stations

Throughout the test period the PCU was tested from various locations throughout the state including Dietrich Camp, Prudhoe Bay, McGrath, Bethel, and Kotzebue. The purpose of testing from these locations was twofold. The first two locations were used during the summer test program and it was

```
                                        AMOS - BIG DELTA

   DATE      3  6 75

                  TIME                           MESSAGE

                  15 9   AMOS SOON
                  1514   AMOS SOON
                  1514   AMOS SOON
                  1523
                  1524   AMOS NOT YET
                  1531
                  1532
                  1538   AMOS NOT YET
                  1541   AMOS NOT YET
                  1541   AMOS NOT YET
                  1545   AMOS NOT YET
                  1546
                  1548   AMOS NOT YET
                  1554   AMOS NOT YET

WAITING TIMES IN MINUTES
                    0     1     2     3     4     5     6     7     8     9    10    11    12    13    14

NO. MESS.           2     0     0     2     1     1     1     0     0     0     2     0     0     0     1

PER CENT DIST    20.0   0.0   0.0  20.0  10.0  10.0  10.0   0.0   0.0   0.0  20.0   0.0   0.0   0.0  10.0

MEAN WAITING TIME =    5.5 MINUTES                    STANDARD  DEVIATION =   4.57

NUMBER OF GOOD MESSAGES =   10.

NUMBER OF BAD MESSAGES =     4

RATIO BETWEEN
                 GOOD/BAD MESSAGES RECEIVED    10. /    4.        = 250.00 PER CENT
TOTAL NUMBER OF MESSAGES RECEIVED =    14

                 GOOD/TOTAL MESSAGES RECEIVED    10. /    14.       =  71.42 PER CENT


                                        AMOS - BIG DELTA

   DATE      3  6 75

                  TIME                           MESSAGE

                  16 4
                  16 9   AMOS NOT YET
                  1612
                  1615
                  1620
                  1631
                  1640   AMOS 20/12/3401/M 000
                  1659   AMOS 20/12/3301/M 000

WAITING TIMES IN MINUTES
                    0     1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19

                   20    21    22    23    24    25    26    27    28    29    30    31

NO. MESS.           0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     1

NO. MESS.           0     0     0     0     0     0     0     0     0     0     0     1

PER CENT LIST     0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0  33.3   0.0   0.0   0.0  33.3

PER CENT DIST     0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0  33.3

MEAN WAITING TIME =   21.6 MINUTES                    STANDARD  DEVIATION =   8.32

NUMBER OF GOOD MESSAGES =    3.

NUMBER OF BAD MESSAGES =     5

RATIO BETWEEN
                 GOOD/BAD MESSAGES RECEIVED     3. /    5.       =  60.00 PER CENT
TOTAL NUMBER OF MESSAGES RECEIVED =    8

                 GOOD/TOTAL MESSAGES RECEIVED    3. /    8.      =  37.50 PER CENT
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Figure 18 Example of computer output for the first step in the analytical procedure used with the AMOS data.

desirable to see if the same difference in communication rate between these two stations and the Fairbanks Station would occur during the winter period. Also when the data from these stations were combined with the data from the other three locations, it should be possible to adequately define the message rate versus distance relationship. Since during the summer test no sites west of Anchorage were used, it was decided to use Bethel, McGrath, and Kotzebue for this portion of the testing.

The specified field procedure called for the base station antenna to be rotated midway between Fairbanks and McGrath for the testing from McGrath; then directed toward Bethel for the testing from there (Note: At this point it was anticipated that reception from Fairbanks would be lost.); and then rotated to midway between Kotzebue and Fairbanks for testing from Kotzebue. With this procedure, both the Fairbanks Station and the other remote stations should be received simultaneously and the results from the remote stations (McGrath and Kotzebue) could be compared with the much larger data base obtained from the Fairbanks Station. No antenna rotation was necessary to simultaneously receive messages from Fairbanks, the Environmental Station, Dietrich Camp, and Prudhoe Bay.

Instead of following the specified procedure, the base station antenna was first rotated midway between McGrath and Bethel. With the antenna at this orientation, the axis of the antenna was at 90° to a line between Fairbanks and Anchorage. During the afternoon hours, i.e., when the testing was performed from McGrath, there was virtually no reception from either of the two stations located in the Fairbanks area. The remote station was then moved and tested from Bethel during the night. During the evening hours, communication was again established with the Fairbanks Station even though the antenna had not been rotated. However, no communication was received from the Environmental Station.

When the base station antenna was rotated for testing from Kotzebue, the magnetic declination was subtracted from, instead of being added to, the desired azmiuth. As a result, the axis of the antenna was oriented almost directly toward Fairbanks and was removed from Kotzebue by almost 55°.

When these alterations in specified procedures are considered, it can be seen that it was not possible to perform the anticipated comparisons. Thus modified analytical procedures had to be used. The results of the various comparisons are summarized in Table 1.

The results of the Summer Test Program clearly indicated that there was a distance effect and that the relationship proposed by Boeing was representative of the field testing in Alaska. From the results summarized in Table 1 one might conclude that there is no distance effect. However, in view of the altered procedure used in orienting the base station antenna, it is felt that no firm statement can be made concerning the effect of distance and communication rate between the base station and any given remote unit. If a relationship does exist, it would appear that it is much less significant thar that shown in the data from the Summer Test Program.

TABLE 1

REMOTE STATION	COMPARED TO	SIGNIFICANTLY SAME	SIGNIFICANTLY DIFFERENT	REMARKS
McGrath	Fairbanks - 1st week hourly means	X		Expected value
Bethel	Fairbanks - 1st week hourly means		X	2-3 times as many good messages Expected value
Kotzebue	Fairbanks - same hour	X		Expected 2-3 times as many Base Station antenna improperly oriented
Kotzebue	Fairbanks - 1st week hourly means	X		Expected 2-3 times as many Base Station antenna improperly oriented
Dietrich,	Fairbanks - same hour		X	Less than Fairbanks Expected 1½-2 times as many
Prudhoe Bay	Fairbanks - same hour non-aurora periods	X		Expected 2-3 times as many Some data lost due to paper jamming of teletype
Prudhoe Bay	Fairbanks - 1st week hourly mean, aurora periods	X		Aurora observed in Fairbanks data but not in Prudhoe Bay data

Aurora Effects

The previous portions of this report clearly indicate that the aurora borealis had a pronounced effect on the operation of the Test Program. In the report by Boeing, it was noted that the adverse aurora effects were present in approximately 11 percent of the hourly time periods. Being a rather small portion of the total time, Boeing chose to exclude these time periods from their analysis of the data. If time were the only consideration, we could concur with such a decision. However, during the 56 hourly periods when adverse aurora effects were observed in the data from the Fairbanks Station, nearly half of the total number of messages from that station were received. The potential impact of these effects on an operational system is such that in the design and operation of a system for use in the high latitudes special consideration must be given to the effects of the aurora even though it may only affect the operations approximately 11% of the time.

The operation of the meteor burst system is based on the premise that the meteor trails located in the 60 to 100km region of the atmosphere act as reflecting surfaces by which a radio signal is reflected or reradiated back toward the earth. The system cannot distinguish between a meteor trail, an aircraft, a satellite, or even the aurora borealis as the reflecting surface. With the meteor trail, the reflecting surface can be envisioned as being a small flat surface encompassing virtually a point in the sky. With such conditions, there is one path that the transmitted signal can follow in completing its travel between base station and remote unit. With the aurora, the reflecting surface can take several different forms: 1) it can be too weak to serve as a reflecting surface; 2) it can be of moderate strength such that it provides a good reflecting surface which encompassed more than just a point in the sky; 3) it can be of moderate strength yet an irregular surface analogous to a broken mirror lying in the sand where each piece reflects the incident light into a different direction; 4) or it can be of strong intensity (either smooth or irregular) such that its strength is great in comparison to the incident radio signal. Each of these categories has a distinct effect on the operation of the meteor burst system and worth discussing on an individual basis.

With the first case, i.e., low level, the presence of the aurora has virtually no effect on the operation of the meteor burst system. However, as the intensity of the aurora increases, a point is reached at which the ionized layer resulting from the aurora is sufficient to be used as a reflecting surface. If the reflecting surface is smooth, there is one small area which will be so positioned that it can reflect the transmitted signal between the base station and any given remote unit. A second small area could act similarly for a different remote unit, and so on. With this condition, the communication between the remote and base stations is enhanced by the presence of a suitable reflective surface. Such an aurora condition can be detected visually and generally exists when the sky or a portion thereof is illuminated with a steady glowing condition. When an oscilloscope is used to monitor the detected HF signal from an antenna, this category of aurora appears as a relatively smooth trace at an elevated intensity.

If, however, the aurora is of a moderate intensity, yet is an irregular surface, then like the broken mirror lying in the sand, the signal is reflected from a number of sources. With the meteor burst system there is sufficient time differential between the signals received via the various multipaths that the true signal becomes scrambled and nonrecognizable. Such a message was classified as an "aurora message" in the reduction of the data. To the visual observer, this category of aurora interference results from both the moving curtain and variable intensity displays. When viewed on an oscilloscope, this type of aurora produces a trace at an elevated level which is highly irregular (i.e., has a lot of "grass").

The last major category of aurora interference is that in which the aurora is of such an intensity that its own emitted radiation is large in comparison to the meteor burst signal. In such situations, the meteor burst signal is lost in the overall radiation signal. To the visual observer this category is recognizable as the very intense displays, either stationary or moving. On the oscilloscope they appear as an elevated intensity, generally with a highly irregular trace (i.e., a lot of "grass").

Both the moderate intensity irregular surface and the high intensity aurora can, and do, cause adverse effects to a meteor burst operation. With the moderate intensity irregular surface type, the remote unit receives a signal from the base station requesting a transmission. However, due to the multipath condition, the message received at the base station has parity errors and thus is interpreted by the base station as a "bad" message. The station continues to probe the remote until a favorable response is received. During the process, the remote unit may send several hundred messages per hour before a good message is received at the base station. This excessive activity on the part of the remote unit can cause a severe power drain on systems operating on a self contained power source, and thus must be considered in the design of such stations.

A second problem that can occur during a period with moderate intensity irregular surface aurora is associated with the probing signal from the base station. Here, the multipath works in reverse. When the base station sends out its coded message the multipath condition results in a false adddress being received at the remote unit. Thus, even though the remote unit was not being called by the base station, it received a message which it interpreted as its address and responded. Here again, the main problem is with the excessive power drain on self contained units.

With the high intensity aurora interference, there are again two major types of problems. First, when the intensity reaches some threshold value, all communication is interrupted. With this condition, the base station can not recognize a fixed pattern in the incoming messages and thus merely interprets them as no message. The second type of problem with the high intensity aurora interference, is that the remote unit can again receive a signal which it interprets as its address and attempts to send a message.

The above discussion is somewhat of an over-simplification of the actual problems encountered in the field. An examination of the base station output data and visual observation in the field show that the condition of the aurora, and thus its interference pattern, is a continuously changing phenomenon that may not be affecting all remote units similarly at a given moment. The data clearly indicates that periods of multipath conditions were of a variable time duration, and often were interrupted by abnormally high communication rates of good messages and/or periods of no communication.

Several conditions noted in the data are of significance in attempting to ascertain the full impact of the aurora interference and also in considering potential methods for overcoming it. On a number of occasions, multipath aurora conditions were noted in the data from the Fairbanks Station but were absent in the messages from the Environmental Station. However, at the same time, the Environmental Station either did not respond or responded very infrequently (in comparison to the large number of multipath communications from the Fairbanks Station). When multipath aurora interference was observed from the Big Delta Station, a similar situation was observed from the Fairbanks Station. Once the Hydro-Met unit associated with the Environmental Station was made inoperative, the Environmental Station and the Fairbanks Station, both responded similarly to multipath aurora interference. When multipath aurora interference was observed at the Fairbanks Station, no interference was observed in the transmissions from Prudhoe Bay.

These and other similar observations of irregularities in the data have raised a number of questions. Although answers to many of these questions are currently not available, several questions are listed here in that they give further insight into some of the factors that must be considered in designing a protective mechanism to overcome the aurora interference.

1. Is it possible that on repeated occurrences a multipath aurora condition could exist in such a way that it would interfere with the Fairbanks Station, yet notaffect the Environmental Station located some 35 miles away?

2. Is it possible that the difference in address codes(5 bit at the Fairbanks Station and 7 bits at the Environmental Station) combined with the Hydro-Met interference desensitized the Environmental Station to such a point that it was not "hearing" the weak multipath signals calling for a transmission which were obviously heard by the Fairbanks Station?

3. When the remote unit was being tested from Prudhoe Bay, a period of approximately 2 hours was encountered when there were a large number of transmissions from the remote unit. Unfortunately, during the same time, Fairbanks was experiencing a multipath condition which resulted in a jamming of the paper on the teletype output. Thus the base station data was lost for this period. In light of the conditions observed with the Environmental Station, was this activity at Prudhoe Bay the result of "false triggering" caused by aurora interference or, due to the considerable difference in distance, was it using the aurora as a suitable reflective surface? Unfortunately, there is no way of telling what actually was happening.

From the above, it should be apparent that during aurora events, some mechanism or procedure must be available whereby the effects of the multipath communication can be filtered out of the system. Boeing has suggested that one alternative is to merely shut down the base station. This would work. However, it would also mean that there would be a considerable time period when the entire system was not operative merely because aurora effects were present at a few of the remote units.

It should also be apparent that the removal of a particular remote unit from the base station polling sequence will not insure that an affected station will not respond. This was clearly shown with the Environmental Station which did respond during aurora events even though it was not being polled.

Therefore, any protective device which may be conceived for removing the adverse interference effect of the multipath aurora must be concerned with the remote receiver. Here, it is conceivable that the required protection can be provided by: 1) a more complicated addressing scheme; 2) a multi-stage sequential addressing; or 3) a simple switch which when a preset number of transmissions are made in a given time window, the remote unit is locked into a standby mode for a predetermined time interval.

GENERAL DISCUSSION

The experience gained from the Summer and Winter Test Programs revealed a number of points concerning the operation of the Boeing Meteor Burst Communication System which are of signifícent value in designing an operational system and which are not yet recorded in any of the previous technical papers concerning meteor burst systems. The conclusions presented in this section are the result of trial-error, cause-effect, and pure deductive reasoning. The scientific studies necessary to support or disapprove these conclusions have, as yet, not been performed. However, it is felt that the field observations are sufficient to support these conclusions.

On several occasions during both the Summer and Winter Test Programs it was found that when the antenna for the remote unit was placed on a support mast 25-30 feet high and anchored adjacent to a building with a metal roof, the communication rate was seriously hampered -- 1/4 to 1/10 the expected value. However, when the mast was moved as little as 8-10 feet from the building, the anticipated communication rate was obtained. This condition occurred even though the separation between metal roof and antenna was theoretically great enough to eliminate the observed interference. Thus, it would appear that when a remote unit is to be housed in a building with a metal roof it is better to provide a free standing antenna mast a short distance from the building than to use one anchored to the building such that the antenna is positioned directly above the metal roof.

The antenna used with the base station was a double yagi having a beam width of approximately 50 degrees. If the antenna was pointed due north, it would illuminate an area of sky approximately 25° on either side of north, or from azimuth 335° through 0° to 25°. The area of sky from approximately 25° through 180° to 335° was either not illuminated or illuminated with a greatly reduced signal. When such antennas are used in an operational system it can be seen that in order to communicate with two remote stations separated by 120°, one of two base station antenna configurations must be used. Either the base station must be equipped with a rotor such that the antenna can be moved from one azimuth to the other, or two separate antennas must be used. With the rotor system, communication with the first station will be lost when the antenna is moved into position to communicate with the second remote unit. With the double antenna system, the base station output power must be doubled in order to maintain the same communication efficiency. If 1000 watts of output power was being supplied to one single antenna, then to keep the same efficiency with a two antenna system 1000 watts of output power must still be supplied to each of the two antennas for a total of 2000 watts for the station. If it is further assumed that the axis of both of the antennas are oriented directly toward each of the remote units, i.e., 120° apart, then there would still be an area 70° wide between the two units which was not being illuminated or illuminated with a greatly reduced signal.

From the above example it can be seen that if it is desirable for a base station to have the capability of communication with remote units spaced at 360° about the station, then either the rotor system or 8 fixed base antennas each having a beam width of 50° would have to be used. In the latter case the total base station output power would have to be (from our example) 8000 watts or 1000 watts per antenna to maintain the same relative power per antenna. Needless to say, the increased station capacity as well as the necessary switching and other support mechanism will greatly increase the cost. As an alternative, the rotor system also has an additional cost over a single fixed antenna system, has the increased operational mechanisms for synchronizing the polling sequence with the movement of the rotor, and has the distinct disadvantage of sequentially losing communication with the various remote units as the axis of the antenna moves around the circle.

The experience gained during both the Summer and Winter Test Programs indicates that the actual problems associated with the orientation of the base station antenna are not nearly as great as might first be envisioned. In the Summer Test, it was shown that the communication rate from a station located 45° from the axis of the antenna was statistically the same as a station located along the axis of the antenna. Thus the effective beam width was approximately 90° and not the specified 50°. During the Winter Test, it was shown that when the antenna was orientated toward Fairbanks, the reception from Kotzebue, located 55° from the axis of the antenna, was statistically the same as that from Fairbanks. If the distance effect was truly present, then the reception from Kotzebue should have been greater than that from Fairbanks and the orientation of the antenna had a countering effect and reduced the rate to a level statistically the same as that from Fairbanks.

A third example which is less significant yet worth mentioning was that encountered when the base station antenna was oriented toward Bethel and reception was received from Fairbanks, 105° removed from the axis of the antenna. Although the total number of messages received from the Fairbanks Station during this portion of the testing was significantly reduced, the waiting time between consecutive <u>good</u> messages was statistically the same as when the antenna was oriented toward the Fairbanks Station. This leads us to believe that the unit power per antenna as used in the test (600-1000 watts) is not mandatory.

These limited examples suggest that the "effective beam width" of the base station antenna is much greater than the specified beam width. This conclusion is also supported by a theoretical consideration of the operation of the system. The basic premise by which the system operates implies that the incident radio signal is reflected or reradiated from the meteor trail in such a way that a change in the vertical path of the signal occurs. Thus, it is equally reasonable to assume that a change in the horizontal path of the signal can, and does, also occur. This change in the horizontal path of the signal results in the effective beam width of the antenna being significantly different from the specified or illuminating beam width of the antenna.

Although limited data is currently available, it would appear that the full 360° around a base station could adequately be served by 4 antennas spaced at 90° intervals all powered by a single 4000 watt transceiver. If the remote units are strategically located, it is possible that as few as three antennas could serve the entire 360° without an appreciable loss in efficiency. With such an arrangement, the cost of the additional fixed-base antennas would not be significantly different from that of a rotor system or possibly less, and would be more than offset by the capability of continuous potential communication with any of the remote units.

In considering the design of a base station, either location or antenna configuration, it is apparent that the distance effect as observed during the Summer Test Program and as recorded by Boeing, is of minor consideration. Since under most operations, the same requirements would be applied to the near stations as are applied to the more distant stations, the increase in communication rate with distance is of little significance in that the design must be based on the worst operating conditions, i.e., the remote unit located 150 to 300 miles from the base station. Thus, if a given design will satisfy the nearby remote units, it may be possible that a decrease in antenna efficiency for a more remote unit would be offset by an increased efficiency resulting from the increased distance.

The last point which needs consideration at this time involves the polling sequence of the base station. During the entire Summer Test and for most of the Winter Test a polling sequence was used whereby a common call was transmitted by the base station. With this type of operation the base station sends out a signal which can basically be interpreted as "anyone who hears me, respond." For a small remote network such a polling sequence should cause no problem. However, when the number of remote units is increased to several hundred, this type of polling can potentially cause serious difficulty. Under such conditions it is possible that several remote units will receive a message to report at the same instant resulting in a number of communications being received at the base station at the same time. The net result is a multipath communication which the base station interprets as a scrambled message. Unfortunately, no one has yet tested a system consisting of several hundred remote units and thus the seriousness of such potential problems is unknown. However, some insight into the magnitude of the problem can be obtained from the results of the Winter Test. If the waiting time distribution function as presented in Figure 9 for the hour with the minimum mean waiting time is extrapolated to 100 milliseconds (0.1 second) it can be seen that approximately 2% of the messages would be received in that waiting time or less. If there are two remote units which are statistically independent yet which have the same distribution of waiting times (the case shown in the Winter Test for all stations except the Environmental Station) then the probability of having both units respond within the same time window is approximately 0.04%.

When the system is expanded to three remote units and the figures cited above are used, it can be seen that the probability of units A & B responding at the same time is 0.04%, the probability of units A & C responding at the same time is 0.04%, and the probability of units B & C responding at the same time is 0.04%. Thus the probability of having a multipath communication is increased to approximately 0.12%. As the number of stations increases, the probability of having a multipath response from more than one station also increases (approximately 4% for 100 remote units). Thus the polling sequence used in this testing program, i.e., "anyone who hears me, respond" cannot be effectively used in an operational system involving more than just a very few remote units. As an alternative, a sequential polling by individual remote unit address or possibly a sequential polling by small groups of remote units, will have to be used on systems containing a large number of remote units. By so doing, the statistics associated with the operation of such a system may be different from those presented here. However, since a large system has never been tested, the applicability of the results presented here is unknown.

It is realized that the extrapolation of the data as presented above is a questionable operation and further, that the conclusions drawn from such an extrapolation often are misleading and incorrect. However, with the amount of information currently available on meteor burst systems it is felt that such an analysis does give further insight into what might be expected as well as highlighting another item which must be considered in the design and operation of a large system.

SUMMARY AND CONCLUSIONS

The Winter Test Program of the Boeing Meteor Burst Communication System consisted of a thirty day period during which a base station located in Anchorage was operated on a continuous basis. For the full test period a remote unit located at the SCS offices in Fairbanks was also in operation. A second remote unit located at the Caribou-Poker Creeks Research Watershed located approximately 35 miles north of Fairbanks was operated for the first three weeks of the test program. In addition to these "permanent" stations, a remote unit was tested for short periods of time from Dietrich Camp, Prudhoe Bay, McGrath, Bethel, Kotzebue, and Big Delta. A total of approximately 40,000 messages were received by the base station and form the basis for the analyses presented in this report.

The data from the Fairbanks Station indicated that a mean waiting time between consecutive good messages varied from a low of approximately 2.0 minutes for the period between 10-11 a.m. to a maximum of approximately 7.0 minutes for the period 5-6 p.m. The anticipated sinusoidal diurnal variation in waiting times was not encountered. Rather, a diurnal relationship was defined whereby a gradual decay function existed for the period of approximately 10 p.m. to 11 a.m. at which time a gradual ascent with a maximum at approximately 6 p.m. occurred. The ascent was followed by a rapid decline until approximately 10 p.m. at which time the function would repeat itself. An analysis of variance was performed on the data and indicated that for the thirty day test period there was no apparent seasonal variation (95% confidence level) even though such an effect was anticipated from previous studies.

The data concerning the effect of distance on the communication rate was inconclusive but it appears that there was no distance effect as had been suggested by previous studies.

The data from the Environmental Station indicated that the system operated at temperatures of at least -28°F with no apparent malfunction. The minimum specified operating temperature as supplied by the manufacturer is -22°F.

The Environmental Station was equipped with a counter for recording the number of times the remote transceiver was switched to the transmit mode. From these data it was determined that for non-aurora periods, it took an average of 2.2 attempts to get one good message through to the base station. When aurora periods were included in these computations, it took an average of nearly 9 attempts to get one good message through to the base station. Thus, it can be seen that for operations in the high latitudes, the frequent occurrence of the aurora can have a pronounced effect on the operation of the system.

The effects of the aurora are highly complex and can both enhance and hinder the operation of the system. Since the aurora can result in a serious power drain on remote units powered by a self-contained power source, and further, since the aurora can affect one station while another station a short distance away is unaffected, it is imperative that some protective device be provided for the remote units associated with an operational system. Since the aurora effects are "remote station selective" the protection device should be with the remote unit and not with the base station. In this way, the maximum use of the system can be made in that remote units unaffected by the aurora disturbance can still be operated either normally or at an enhanced level while the adversely affected stations are temporarily shut down.

On several occasions during the test program, the Boeing Hydro-Met Unit did not provide a proper update-message to the meteor burst system. However, in an equal number of cases (4) the NWS DARDC also failed to provide a proper up-date message. Except for minor difficulties with the research equipment as discussed periodically throughout the text, no significant malfunctions of the equipment were encountered.

A test was performed using an inverted "V" antenna with the remote unit in place of the standard dipole. It was found that at the 95% confidence level there was no apparent difference in the communication rate regardless of the antenna used.

The results of the Winter Test indicate that a meteor burst system properly designed and operated could meet many of the envisioned telemetry needs for the acquisition of environmental data in Alaska.

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