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# COMPUTER PROGRAM COMPATIBLE WITH A LASER NEPHELOMETER

**FINAL REPORT**

For Period 20 May, 1974 thru 20 May, 1975

ERT Project No. P-821

GSFC Contract No. NAS 5-20496

June 1975

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16. Abstract  <p>The GSFC Laser Nephelometer data system was updated to provide magnetic tape recording of data, and real-time or "near" real-time processing of data to provide particle size distribution and liquid water content. Digital circuits were provided to interface the laser nephelometer to a Data General Nova 1200 mini-computer. Communications are via a teletypewriter. A dual Line Magnetic Tape System is used for program storage and data recording.</p> <p>Operational programs utilize the Data General Real-Time Operating System (RTOS) and the ERT AIRMAP Real-Time Operating System (ARTS). The programs provide for acquiring data from the Laser Nephelometer, acquiring data from auxiliary sources, keeping time, performing real-time calculations, recording data and communicating with the teletypewriter.</p>			
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## TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION	1
2. HARDWARE CONFIGURATION	2
2.1 Data Processing and Recording System	2
2.2 Laser Nephelometer Interface	2
2.3 Expansion Potential	4
3. SOFTWARE MODULES	5
3.1 Real-Time Data Acquisition and Recording Software	5
3.2 Post Real-Time Software	7
4. SYSTEM OPERATING MANUAL	8
APPENDIX A Nephelometer Data Acquisition System Manual	9
A.1. GENERAL DESCRIPTION	10
A.2 REAL-TIME SOFTWARE OPERATION	11
A.3 CALCULATIONS	17
A.4 FIELD VERIFICATION OF DATA TAPES	20
A.5 TROUBLESHOOTING THE REAL-TIME SOFTWARE PACKAGE	23
A.6 TROUBLESHOOTING THE NEPHELOMETER INTERFACE	26

## 1. INTRODUCTION

The objective of this program was to update the data system on the GSFC laser nephelometer to provide the capabilities to (1) record the data on magnetic tape, (2) examine the data on a real-time - quick look basis, and (3) have a quick turn around on the data reduction. In order to accomplish this task, it was necessary to accomplish the following hardware and software subtasks: (1) procure a cost effective data processing and recording system, (2) interface the laser nephelometer with the data system, and (3) write and test the data processing programs required to reduce the nephelometer data.

## 2. HARDWARE CONFIGURATION

The hardware configuration for the Laser Nephelometer Data System is shown in Figure 1. It consists of the data processing and recording system and the laser nephelometer interface.

### 2.1 Data Processing and Recording System

The data processing and recording system consists of a Data General Nova 1200 central processing unit with 8K of core memory, a dual transport Linc magnetic tape system, and an ASR 33 teletype.

The Nova 1200 is the heart of the system. It provides (1) scheduling of all data acquisition, recording, and reports, (2) control of the dual Linc tapes and the ASR 33 teletype, and (3) calculations capability for real time data reduction. In addition, the Nova 1200 has power fail/automatic restart circuits which provide an orderly shutdown of the experiment in the event of power failure and automatic restart of the program upon power up.

The dual Linc tape provides a very highly reliable (greater than  $10^{10}$  bits per bit error) magnetic tape storage system with a capacity of roughly 12,000 nephelometer samples (167,936 sixteen bit words) per reel. At a sampling rate of 33 Hertz, a reel will be filled in roughly 6 minutes. The dual transports provide continuous recording by switching to the dormant reel when the current reel is filled. The Linc system also provides for rapid loading of system programs and was useful as a program development tool.

The ASR 33 teletype provides a terminal for communication with the experimenter. This is necessary to establish various experiment parameters such as data sampling rate and aircraft velocity and to present reports of the real time data reduction.

### 2.2 Laser Nephelometer Interface

The laser nephelometer is interfaced to the Nova 1200 via one of seven Nova I/O slots. The interface consists of (1) 13 sixteen bit counters which can be sampled and reset by the CPU, (2) an interrupt line driven by the laser nephelometer RESET signal, and (3) gating circuits for

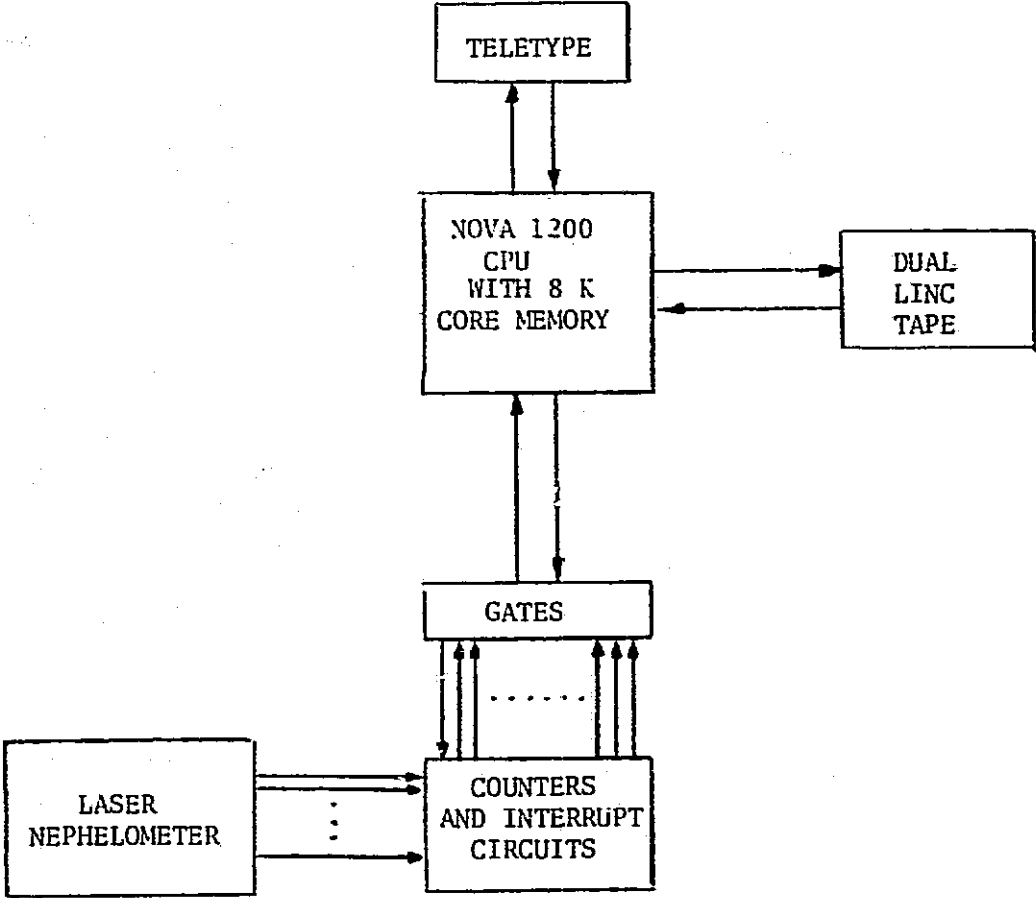


Figure 1 Laser Nephelometer Data System Hardware Configuration



access to the CPU. Twelve of the counters are incremented in parallel with the light display on the old nephelometer data system. The thirteenth counter is incremented when any of the other counters is incremented and therefore holds the total of all counts. The interrupt line is necessary to signal the Nova 1200 that the counters should be sampled and cleared. This interrupt is required to maintain synchronization with the light display during tests and to avoid data loss due to counter overflow.

### 2.3 Expansion Potential

If it is later desired to record aircraft parameters simultaneously with the nephelometer data, a flexible interface chassis for collecting data from auxiliary digital and analog sources can be added at minimal expense.

### 3. SOFTWARE MODULES

The software modules developed for the laser nephelometer consist of a real-time system for data acquisition and recording, a post real-time program for verifying data tapes, and diagnostic programs for troubleshooting the laser nephelometer interface.

#### 3.1 Real-Time Data Acquisition and Recording Software

The real-time software package runs under Data General Co's Real-Time Operating System (RTOS) with the assistance of ERT's AIRMAP<sup>®</sup> Real-Time Operating System (ARTS). These operating systems allow several independent tasks to be scheduled and executed virtually simultaneously. The laser nephelometer's tasking structure is shown in Figure 2.

A Teletype Conversation Task is used to initialize the experiment and provides a method for the user to change parameters while the experiment is in progress. Once the experiment has been initialized, the Clock Task maintains time of day to a resolution of 1 millisecond and schedules data sampling and report generation at intervals specified by the user.

The Data Acquisition Task is executed either on the Clock Task's schedule or asynchronously upon RESET interrupt from the nephelometer. The data sample is taken, and, if RESET is requested, the interface counters are reset to zero. Differential counts and time are calculated from the previous sample and sent to the Linc Tape Task for recording and to the Real Time Calculations Task for integration into subsequent calculations and reports.

The Linc Tape Task is the data recording module. Differential counts and time are stored in one of a pair of 256 word buffers. When a buffer is filled, the Linc Tape hardware is activated for recording the buffer's data onto magnetic tape; subsequent data are stored in the alternate buffer. Usage of tape is monitored and switch-off to the dormant transport occurs when the reel on the current transport is filled.

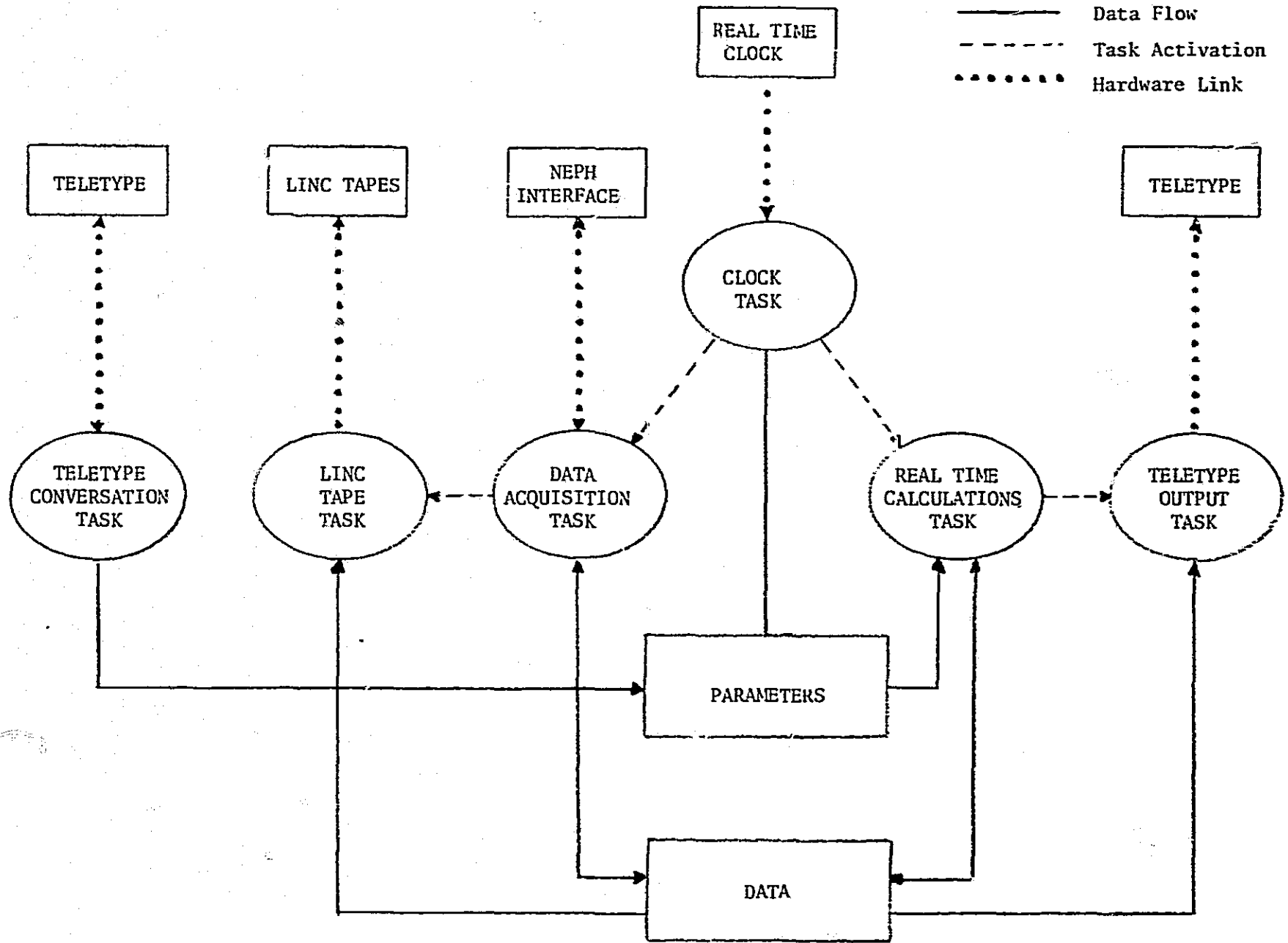


Figure 2 Real-Time Software Task Structure

The Real Calculations Task operates on integrated counts and time since the previous calculation. The counts are corrected for partial droplets entering the laser nephelometer's sample volume. Sample volume is calculated from aircraft velocity, elapsed time, and sample volume cross-sectional area. From calibrated counts, sample volume, and sample bin diameters, number density (counts/cubic centimeter), number density per diameter interval (counts/cubic centimeter/micron), and liquid water (grams/cubic meter) are calculated for each bin. Total number density and total liquid water are calculated from the individual bin totals.

The Teletype Output Task is activated when real-time calculations have been completed. The calculated results are displayed and control is returned to the task scheduler.

The real-time software package was tested by simulating data taken in the Bering Sea Expedition. A comparison of results calculated from the old laser nephelometer data system and those calculated by the real-time software showed agreement limited only by truncation errors in the real-time software. The truncation errors are well within the accuracy of the measuring device.

### 3.2 Post Real-Time Software

Programs are available which provide teletype listings of all or any part of a data tape. These programs are non-real-time and run under the Linc Tape Operating System (LTOS).

Diagnostic programs were written to troubleshoot and debug the laser nephelometer interface. These programs allow field testing of the interface and localization of circuit problem areas.

#### 4. SYSTEM OPERATING MANUAL

A manual on the use of the Laser Nephelometer Data Acquisition System was prepared. The body of the manual which describes use of the real-time software for data acquisition and recording, post-real time software for verifying data tapes, and diagnostic programs for troubleshooting the laser nephelometer interface is attached. Supporting documentation, including an RTOS manual, an ARTS manual, listings of the real-time software, load map of the real-time software, and circuit diagrams of the laser nephelometer interface, are attached to the manual as Appendices.

APPENDIX A  
NEPHELOMETER  
DATA ACQUISITION SYSTEM  
MANUAL  
(Without Appendices)

## A.1. GENERAL DESCRIPTION

The Nephelometer Data Acquisition System consists of a Nova 1200 mini-computer with 8K of memory, ASR 33 teletype, dual transport Linc tape, a real-time software package for data acquisition and recording, post real-time programs for data verification, and diagnostic programs for troubleshooting the interface between the nephelometer and the Nova 1200. All software programs are stored on Linc tapes and are loaded by the Linc Tape Operating System (LTOS).

The real-time software package runs with the assistance of Data General's Real-Time Operating System (RTOS, see Appendix A) and ERT's AIRMAP Real-Time Operating System (ARTS, see Appendix B). Included in ARTS is a Teletype Conversation Routine which allows the operator to verify and/or modify system parameters, by teletype interaction, while the experiment is in progress. The Teletype Conversation Routine also provides for an orderly initialization, termination, and reinitialization of the real time software package.

In addition to the Teletype Conversation Routine, the real-time software multitask environment consists of a clock task which maintains time to a resolution of one millisecond and schedules data samples, a nephelometer interface handler which requests a data sample in the event of nephelometer reset, a Linc Tape Write task which buffers data and controls transfers to the Linc tape via the Nova data channel, a Data Acquisition task which samples the nephelometer interface counters and transfers differential counts (since the previous sample) to the Linc Tape Write task, a Real-Time Calculations task which calibrates the raw data counts and calculates the sample's various physical characteristics, and a Teletype Output task which presents the results of the real-time calculations on the teletype.

## A.2. REAL-TIME SOFTWARE OPERATION

Normal real-time operation of the Nephelometer Data Acquisition System can be separated into four categories:

- 1) program loading and experiment initialization
- 2) parameter verification and/or modification
- 3) servicing data tapes
- 4) experiment termination and reinitialization

In the descriptions that follow, "↓" designates a teletype carriage return typed by the operator.

### A.2.1 Program Loading and Experiment Initialization

With all system hardware powered up and properly interconnected, the real-time software can be loaded through LTOS as follows. With the Write Protect ON, mount a Linc tape containing the savefile NEPH1 onto Linc tape transport 0 and bootstrap (see Appendix C) the Nova 1200 through LTOS. Eventually, the LTOS executive will gain control of the CPU and will request executive action by typing "EXEC?". The operator should respond by typing "NEPH1↓". In the event of operator error, his response can be deleted by typing the "esc" character; if "esc" fails to restore the "EXEC?" query, the procedure must be restarted at the bootstrap.

NEPH1 will automatically load from the Linc tape and HALT the computer. The operator should remove the tape on drive 0 and store it safely away, mount data tapes onto both transports, verify tape tension and Write Protect OFF on both transports, and depress the CONTINUE switch on the Nova 1200 console. RTOS will be initialized and confirmed with a teletype message, the Linc tapes will be rewound, and ARTS will be initialized and confirmed with a teletype message. Control then passes to the Teletype Conversation Routine which requests the date and time. After the time has been entered, the Teletype Conversation Routine requests further instruction by typing "READY" followed by an asterisk. If the operator is satisfied with the default values of the system parameters, he can proceed with the experiment by typing "XEQ↓". Otherwise, the operator can verify and/or modify



system parameters. Teletype interaction for Program Loading and Experiment Initialization is illustrated in Figure A.1

### A.2.2 Parameter Verification and Modification

All system parameters are available in the system Option table which is accessible through the Teletype Conversation Routine. The Teletype Conversation Routine gains control of the processor at initialization time as described in A.2.1 or during the experiment by simultaneously depressing the teletype keys "CTRL" and "C" ("↑C"). At initialization time, the experiment does not start until "XEQ↓" is typed in response to "READY". However, once the experiment has started, it will run simultaneously with the Teletype Conversation Routine.

The Option table is accessed by typing "OPTS↓" in response to "READY". OPTS will request further instruction by typing "ENTER OPTION: VALUE" followed by an asterisk prompt. The operator can then type an octal option number followed by "?" or ":". The "?" will cause the option's octal value to be typed; the ":" causes an asterisk prompt to be typed, after which the operator must enter a new octal value followed by "↓". To exit OPTS, respond with "↓" when queried for option number. The teletype interaction for Parameter Verification and Modification is illustrated in Figure A.2.

A list of option numbers, the corresponding parameter, and the default value of that parameter is given in Table A.1. Options 1, 2, 3, 34, 36, 37 can be modified at any time with the experiment continuing as modified. All other options should be modified only when the experiment is stopped; the experiment should then be restarted. If initialization is still in progress (i.e. "XEQ" has not been typed yet), restart can be accomplished by responding "START" to the "READY" query. Otherwise, restart by resetting option 37 to zero.

### A.2.3 Servicing Data Tapes

Data is accumulated by the real-time software in a pair of 256 word data buffers. When a buffer becomes filled, it is automatically dumped to the Linc tape in use.

When a tape is filled, the software automatically switches to the other tape for subsequent recording and rings the teletype bell ten times. The operator should rewind and remove the filled tape, mount a new data tape

37377	←	LTOS RESTART Address	} Bootstrap Outputs
02 TAPES	←	Number of Tensioned Tapes	
-EXEC-? NEPH2	←	Erroneous Response, Type "esc"	
-EXEC-? NEPH1	←	Load NEPH1	
RTOS REV 3.00	←	RTOS Initialization Confirmation	
ARTS 3 REV 101	←	ARTS Initialization Confirmation	
DATE MM/DD/YY	*3/12/75	←	Teletype Conversation Routine Initialization
TIME HH:MM	*14:00		
READY			
*XEQ	←	Start Experiment	

Figure 1 Example of Teletype Interaction for Program Loading and Experiment Initialization

```

Experiment Running, Type ↑C
READY ← Teletype Conversation Routine Response
*OPTS ← Operator Accesses Option Table
ENTER OPTION: VALUE ← OPTS Response
*1? 001750
*2? 000764
*3? 000000
*4? 007440
*5? 007440
*6? 000000
*7? 001220
*10? 000000 ← Operator Verifies all Options
*11? 000206
*12? 000670
*34? 000036
*35? 000620
*36? 000000
*37? 000000
*1: *764 ← Operator Modifies Option 1, Experiment
*57: *1 ← Operator Terminates Experiment
*

```

14:15 ← Final Real Time Output

BIN	BIN DIAMETERS (UM)	NUM DENSITY #/(CM**3)	NUM DENSITY/INTERVAL #/(CM**3)/UM	LIQUID WATER G/(M**3)
01	4.40-- 5.89	00000.000	00000.000	000.0000
02	5.89-- 7.90	00000.000	00000.000	000.0000
03	7.90-- 10.58	00000.000	00000.000	000.0000
04	10.58-- 14.18	00000.000	00000.000	000.0000
05	14.18-- 19.00	00000.000	00000.000	000.0000
06	19.00-- 25.47	00000.000	00000.000	000.0000
07	25.47-- 34.13	00000.000	00000.000	000.0000
08	34.13-- 45.73	00000.000	00000.000	000.0000
09	45.73-- 61.28	00000.000	00000.000	000.0000
10	61.28-- 82.12	00000.000	00000.000	000.0000
11	82.12--110.05	00000.000	00000.000	000.0000
12	110.05--111.05	00000.000	00000.000	000.0000
13	4.40--111.05	00000.000	00000.000	000.0000
TOTAL NUMBER DENSITY		00000.000	TOTAL LIQUID WATY	000.0000

```

37 : *0 ← Operator Restarts Experiment

```

RTOS REV 3.00

ARTS 3 REV 101

DATE MM/DD/YY \*3/12/75

TIME HH:MM \*14:25

```

READY
*OPTS ← Operator Accesses Option Table
ENTER OPTION:VALUE
*12: *620 ← Operator Modifies Option 12, Experiment
* ← Operator Exits OPTS not Running Yet

```

```

READY
*XEQ ← Start Experiment

```

Figure 2 Example of Teletype Interaction for Parameter Verification and Modification

TABLE 1  
REAL-TIME NEPHELOMETER SOFTWARE OPTIONS

OPTION	PARAMETER DESCRIPTION (Units)	DEFAULT VALUE
1	Sampling Interval (milliseconds)	$1750_8 = 1000_{10}$
2	Aircraft Velocity (knots)	$764_8 = 500_{10}$
3	Experiment Sequence Number	0
4	Initialize Nephelometer Flag (if 0 at initialization time, nephelometer interface counters will be reset, flag will be set nonzero)	0
5	Initialize Linc Flag (if 0 at initialization time, the Linc tapes will be rewound and subsequent recording will start at tape 0, block 0; flag will be set nonzero)	0
6	Linc Drive in use, updated automatically	0
7	Linc Tape Block Capacity	$1220_8 = 656_{10}$
10	Linc Tape I.D. Number, updated automatically	0
11	Geometric Progression Multiplier for calculating nephelometer bin diameters (multiplier *100)	$206_8 = 134_{10}$
12	Minimum Detectable Droplet Diameter ( $\mu$ *100)	$670_8 = 440_{10}$
34	Delay between Teletype Outputs (seconds)	$36_8 = 30_{10}$
35	Equivalent Crosssectional Area of Nephelometer Sample Volume (millimeters * millimeters * 1000)	$620_8 = 400_{10}$
36	Abort Teletype Output Flag (teletype output of real-time calculations will be aborted if nonzero)	0
37	End Experiment Flag (experiment will be ended if nonzero, experiment will be restarted when reset to zero)	0

With the reflective marker well to the left of the head, and verify tape tension and Write Protect OFF. The filled data tape should be marked and stored for further processing.

The minimum allowable sample interval (Option 1) is 30 milliseconds. This sample rate will fill a 656 block Linc tape in roughly six minutes.

Sample intervals less than 30 milliseconds will cause RTOS system errors (see Section 5) as attempts are made to start the Linc Tape Write task before it has finished its previous transfer.

In the event of power failure, be sure that tension is restored to the Linc tapes before the experiment is restarted.

#### 2.4 Experiment Termination

Once in progress, the experiment can be terminated by setting Option 37 nonzero. The unfilled part of the current Linc tape data buffer will be filled with random data. The buffer will be dumped, and the current real-time output will be completed, (see Figure 2). The system will then continuously check Option 37 for a restart request.

At this point, the operator can change system parameters via the Teletype Conversation Routine and change data tapes. Upon restart, if Option 5 has been reset to zero, the system will rewind both Linc tapes and start recording on Linc tape 0, block 0. Otherwise, the system will start recording on the Linc tape designated in Option 6 at the block number following the last block recorded.

### 3. CALCULATIONS

#### 3.1 Bin Diameters

The droplet diameters associated with each nephelometer bin are calculated by geometric progression with a multiplier of 1.34. The expression for the largest diameter in each bin is:

$$a_i = a_0 r^i$$

where  $a_i$  is the upper diameter limit of the  $i$ th bin in microns

$i$  is the bin number,  $i = 1, 11$

$a_0$  is the lower diameter limit of the first bin in microns

$r$  is the geometric progression multiplier

For the purposes of calculations  $a_{12} = a_{11} + 1$ .

Bin diameter intervals are calculated by:

$$\Delta D_i = \begin{cases} a_i - a_{i-1}, & i = 1, 12 \\ a_{12} - a_0, & i = 13 \end{cases}$$

#### 3.2 Calibrations

In order to eliminate the effects of partial droplets entering the sample volume, the raw count totals are calibrated as follows:

1) Let  $C_i$  = the counts in the  $i$ th bin, and

$K_k$  ( $k = 0, 7$ ) be the following calibration constants:

$$K_0 = \frac{1000}{694}$$

$$K_5 = \frac{35}{1000}$$

$$K_1 = \frac{107}{1000}$$

$$K_6 = \frac{49}{1000}$$

$$K_2 = \frac{46}{1000}$$

$$K_7 = \frac{18}{1000}$$

$$K_3 = \frac{25}{1000}$$

$$K_4 = \frac{19}{1000}$$

2) Find the first  $i$  for which  $C_i > 0$ ,  $i = 12, 1$

3) For each  $j = i, 1$ , let  $k = 1, 7$ , then

$$A_j = C_j K_0$$

$$C_j = A_j$$

$$B_{(j-k)} = \begin{cases} C_{(j-k)} - C_j K_k & \text{for } C_j K_k \leq C_{(j-k)} \\ 0 & \text{for } C_j K_k > C_{(j-k)} \end{cases}$$

$$C_{(j-k)} = \begin{cases} B_{(j-k)} & \text{for } (j-k) > 0 \\ \text{undefined} & \text{for } (j-k) \leq 0 \end{cases}$$

This sequence of calculations will increase the counts in a given bin and decrease the counts in subsequent lower bins as is appropriate from calibration experiments conducted in the spring of 1973. (See Appendix D).

### 3.3 Calculation of Cloud Water Structure

In order to determine the water structure of the sampled volume, the raw data counts must first be calibrated as described in 3.2. Sample volume in cubic centimeters is then calculated from equivalent crosssectional area of the sample volume in millimeters squared (Option 35), aircraft velocity in knots (Option 2), and elapsed time since the previous calculation in seconds.

$$V(\text{cm}^3) = 0.5148 \times A(\text{mm}^2) \times \text{Vel (knots)} \times t(\text{sec})$$

From calibrated counts, volume, and the bin diameter intervals calculated in 3.1, droplet number density in  $\#/\text{cm}^3$ , droplet number density per micron diameter interval in  $\#/\text{cm}^3/\mu$ , and liquid water in  $\text{g}/\text{m}^3$  are calculated for each bin.

1) Number Density

$$N_i = \frac{C_i}{V} \left( \frac{\#}{\text{cm}^3} \right), \quad i = 1, 13$$

2) Number Density per Mircon Diameter Interval

$$\frac{N_i}{\Delta D_i} = \frac{N_i}{\Delta D_i} \left( \frac{\#}{\text{cm}^3 \mu} \right), \quad i = 1, 13$$

3) Liquid Water

$$W_i = \frac{4}{3} \pi (r_{av})^3 \frac{C_i}{V} \times (\text{Density of Water})$$

$$W_i = \frac{4}{3} \pi \left( \frac{\Delta D_i}{40000} \right)^3 N_i \times \left( 1 \frac{\text{g}}{\text{cm}^3} \right)$$

$$W_i = \frac{4}{3} \pi \frac{\Delta D_i^3}{400} N_i \frac{\text{g}}{\text{m}^3} \quad i = 1, 12$$

From number density and liquid water for bins 1 through 12, total number density and total liquid water are calculated

$$1) N_T = \sum_{i=1}^{12} N_i \left( \frac{\#}{\text{cm}^3} \right)$$

$$2) W_T = \sum_{i=1}^{12} W_i \left( \frac{\text{g}}{\text{m}^3} \right)$$

As a check,  $N_{13}$  should equal  $N_T$ .



## 4. FIELD VERIFICATION OF DATA TAPES

### 4.1 Listing Recorded Data

Data verification is accomplished by reading data from a data tape into memory and listing on the teletype. Reading is accomplished by the LTOS savefile KBEX. Listing is accomplished by a debugger search of memory. The procedure is as follows:

- 1) Mount a tape with the LTOS savefiles DEBUG and KBEX onto drive 0; mount a data tape onto drive 1; verify Write Protect ON and tape tension on both drives.
- 2) Bootstrap the Nova 1200 through LTOS (see Appendix C).
- 3) Load DEBUG by responding "DEBUG↵" to the "EXEC?" query.
- 4) Restart the Nova 1200 from the console by entering the LTOS restart address into the switches and depressing "RESET", then "START".
- 5) Load KBEX by responding "KBEX↵" to the "EXEC?" query.
- 6) Using KBEX (see Appendix E), load up to  $16_8$  blocks of data from the data tape into memory starting at location  $1000_8$ .
- 7) Calculate the maximum memory location used for data by:
$$N_8 = 777_8 + (\text{number of blocks loaded})_8 * 400_8$$
- 8) Halt program execution and restart at location  $10000_8$ ; the debugger now has CPU control.
- 9) Type "esc =↵"; then list data by typing " $1000 < N_8$  esc S", where  $N_8$  is the address calculated in step 7.
- 10) Further data verification can be accomplished by repeating this procedure from step 4; data tapes can be changed any time after completing step 6.

## 4.2 Data Format

Data is recorded in binary format preceded by a six character ASCII identifier. The ASCII identifier is packed into three consecutive 16 bit words. These words are differentiated from data by setting their most significant bit (bit 0) to 1. By circuitry constraints in the nephelometer interface electronics, it is not possible for three consecutive data words within a sample to all have bit 0 set to 1. A list of each identifier name, its six characters, a description of the subsequent data, and its frequency of occurrence is given in Table 2.

TABLE 2

## NEPHELOMETER DATA IDENTIFIERS

Identifier Name	Identifier Characters	Subsequent Data	Occurrence of Identifier
Beginning of Experiment	SSSSS	All experiment data	Beginning of Experiment
Parameter Change	IIIIII	Sampling Interval, Velocity, Sequence Number, and Time (msec, sec, min, hr, day of year, year): 9 data words	Beginning of Experiment and whenever Sample Interval, Velocity, or Sequence Number are changed
Elapsed Time	TICTOC	Elapsed time since last data sample (msec): 1 data word	Each nephelometer reset
Data	DDDDDD	Data Samples (consecutive groups of 13 differential count totals)	Following the Subsequent Data of any other Identifier(s)
Continue Tape	CCCCii	ii is continuation tape number	The start of each additional magnetic tape used in an experiment
End of Experiment	EEEEEE	Random data to fill the present Linc write buffer	End of Experiment

## 5. TROUBLESHOOTING THE REAL-TIME SOFTWARE PACKAGE

### 5.1 Error Indicators

There are two types of software error indicators:

- 1) Before the ARTS initialization, errors are indicated by a halt of execution. Halts are indicated by the RUN light on the Nova 1200 console being OFF. The absolute address of the memory location following the halt will appear in the address lights. An error code can be displayed in the data lights by depressing AC2 examine. Execution can be continued by depressing CONTINUE on the Nova 1200 console.
- 2) After ARTS initialization, an error message including the address following the error and the error code are typed and execution is automatically resumed.

### 5.2 Error Codes

Error codes consist of all RTOS error codes (see Appendix A, pp. A-7, A-8) plus a Linc tape status error code (177776). Common Linc tape errors are lack of tape tension or Write Protect ON during a write operation. The specific state of Linc status can be examined in absolute memory at address IOPAK (see Section 5.3). Status states are indicated by the bit structure given in Table 3. For more details on Linc status, see the listing of LDCH in Appendix F.

### 5.3 Program Listings and Load Map

Program listings and a load map for the real-time nephelometer software are provided in Appendices F and G, respectively. The combination of these Appendices can locate the absolute address of any line of the software package as follows. The load map provides a list of the absolute octal address of all global symbols; the format is:

symbol (up to 5 characters)    octal address    (6 octal numbers)

TABLE 3  
LINC STATUS BITS

<u>BIT</u>	<u>STATUS</u>
0	Drive not ready, check tape tension
1	Write protect violation
2	Checksum error
3	Data Channel late, hardware problem
4	Interrupt late, software took longer than 60 msec to respond to Linc's interrupt
15	Last block processed; if no other bits are up, transfer was completed without detectable error.

Each program listing identifies its global symbols by a ".ENT symbol<sub>1</sub>, symbol<sub>2</sub>, . . ., symbol<sub>n</sub>". In addition, each line of code is prefixed with a relative octal address, designated "address". To determine the absolute address of any line of code, simply find a global symbol near that code, look up the global symbol's absolute address in the load map, from the listings calculate the relative displacement of the code from the global symbol, and add the relative displacement of the code to the absolute address of the global symbol.

#### 5.4 Examining or Editing the Real-Time Software Package

The ability to examine or edit any line of code in memory is available by entering the Teletype Conversation Routine (by typing "↑C") and responding "EDIT↓" to the "READY" query. EDIT (see Appendix B) will respond with "ENTER LOCATION: CONTENTS". The location is the absolute address of the code of interest as calculated in 5.3. The remainder of the response is "?" or ":". Typing "?" will cause the location's octal value to be typed; the ":" causes an asterisk prompt to be typed, after which the operator must enter a new octal value followed by "↓".

## 6. TROUBLESHOOTING THE NEPHELOMETER INTERFACE

Diagnostic software for troubleshooting the nephelometer interface is available in the LTOS savefiles NFTEST and NFDEMO. Bootstrap the Nova 1200 through the Linc tape containing NFTEST and NFDEMO. To load NFTEST, respond "NFTEST" to the "EXEC?" query. Once NFTEST gains CPU control, type "START esc R". From this point, NFTEST is self explanatory. Used in conjunction with the circuit diagrams in Appendix H, NFTEST will localize any problem areas in the interface circuitry.

To load NFDEMO, respond with "NFDEMO" to the "EXEC?" query. Once NFDEMO gains CPU control, type "START esc R". From this point, NFDEMO is self explanatory. Used in conjunction with an external source of differential voltage pulses (a pulse occurrence is defined as the signal line of a twisted pair being positive with respect to the reference line, a non occurrence, is defined as the signal line being negative with respect to the reference line), NFDEMO will verify the operation of each interface counter.