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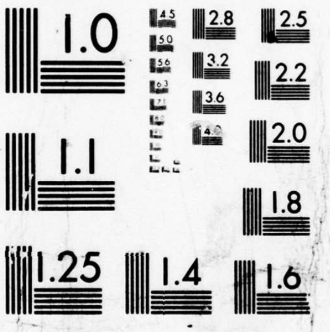
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REPORT NO. FAA-RD-75-65

THE DEVELOPMENT OF A SIGNAL DATA CONVERTER FOR AN AIRPORT VISIBILITY MEASURING SYSTEM

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16. Abstract

The Optical Devices Group at the Transportation Systems Center has been involved in the development of a breadboard Airport Visibility System (ARVIS) for the FAA since FY 72. One major subsystem in the ARVIS is the Signal Data Converter whose characteristics were initially identified in a report (DOT-TSC-FAA-72-1) titled "Characters of a Signal Data Converter for a Multi-Runway Visibility Measuring System," October 1971. Various aspects relative to the determination of RVR have been reviewed and efficient algorithms developed for the computation of RVR from Allard's and Koschmeider's Law. A sixteen bit wordlength has been established as necessary to provide adequate range and accuracy in the determination of RVR.

A breadboard ARVIS was designed and built. Software was developed and parameters representative of various airport operational situations synthesized, exercised and verified, adequately demonstrating the feasibility and versatility of the proposed ARVIS. There remains the ARVIS field testing.

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PREFACE

runway visual range

This report briefly describes the evolution of the FAA/NBS RVR transmissometer system into a breadboard Airport Visibility Measuring System (ARVIS) which has been laboratory tested and which will undergo field tests at the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, NJ during 1975.

Appendix I of this report documents in detail the development of a Signal Data Converter Unit (SDCU) as a replacement for the SDCU used in the FAA/NBS RVR system.

Appendix II describes an analog computer for calculating RVR. Appendix II was prepared by Joseph Horner, TSC.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Definition
ALCH	approach light contact light
ARVIS	airport visibility system
CPCU	central processor and control unit
CSDL	Charles Stark Draper Laboratory, Inc.
ILS	instrument landing system
LED	Light emitting diode
MOD I	modification I
MOD II	modification II
MOD III	modification III
MOD IV	modification IV
NAFEC	National Aviation Facilities Experimental Center
RVR	runway visual range
RVV	runway visibility value
SDCU	signal data converter unit
SVR	slant visual range
TVR	taxi visual range

1. INTRODUCTION

The Transportation Systems Center (TSC) of the Department of Transportation is engaged in a continuing program for the Federal Aviation Administration titled "Airport Visibility Measuring Systems".

This report, in compliance with the Project Plan Agreement (PPA) FAA-515, summarizes the results and recommendations on one of the tasks under the program. The specific task reads as follows:

"Based on the expectation that newer systems will evolve for the measurement of RVR and probably SVR and that instrumentation at multi-runway airports will consist of numerous and varied installations and that the periodicity of update of the observables will increase, the inadequacy of present day signal data converter equipment is apparent. To this end a set of performance characteristics for an airport visibility SIGNAL DATA CONVERTER UNIT (SDCU) shall be developed. The display of the observables shall govern the establishment of SDCU characteristics to the extent that sufficient visibility information shall be available for presentation of operating minima associated with landing categories through CAT III."

TSC has developed and laboratory tested a SDCU (Reference 1) under contract* to the C.S. Draper Laboratory (see Appendix I). It has prepared also a specification to facilitate the procurement of an engineering prototype model for an operational test program and submitted it under different cover. It suggested that the procurement of an SDCU be made as part of an ARVIS including a modified 75-foot baseline transmissometer.

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*DOT/TSC 460

2. AN EVOLUTION FROM THE PRESENT FAA RVR SYSTEM TO AN AIRPORT VISIBILITY MEASURING SYSTEM

An earlier report (Reference 2) summarizes the TSC study which resulted in the definition of characteristics for an SDCU for use in airport visibility measuring systems. The study objective was stated as follows:

"Characteristics will be defined for a signal data converter for computing visibility values from inputs from several transmissometers with reference to several kinds of target lights (e.g., centerline lights, approach lights, edge lights, taxiing lights)."

Economical and operational considerations led the TSC work to an evolutionary process from the present FAA RVR system to an ARVIS. The full system is expected to be reached after a 4-step modification process (Figure 2-1).

The first step in this modification (MOD I) consists of the modernization of present transmissometers (projector power supply and receiver) by using solid state circuitry and components. The second step (MOD II) will consist of, in addition to MOD I, the substitution of the present RVR computer with a SDCU and teletype with the capability of handling the simultaneous signals from several transmissometers distributed along runways.

The third modification (MOD III) implies a system approach to the airport visibility measurements and reporting. By considering the airport as the system, all visibility measuring sensors in the airport, all light systems used as visual cues, and sky background luminance sensor are integrated in a true ARVIS. The ARVIS is a software oriented system in which performance characteristics (frequency of RVR updating, different processing of visibility data, modification of display data in accordance to specific airport needs, etc.) can be changed without changes in hardware.

The implementation of MOD III consists of the expansion of the MOD II SDCU to a Central Processor and Control Unit (CPCU), the replacement of the MOD I (or MOD II) receiver for one with the

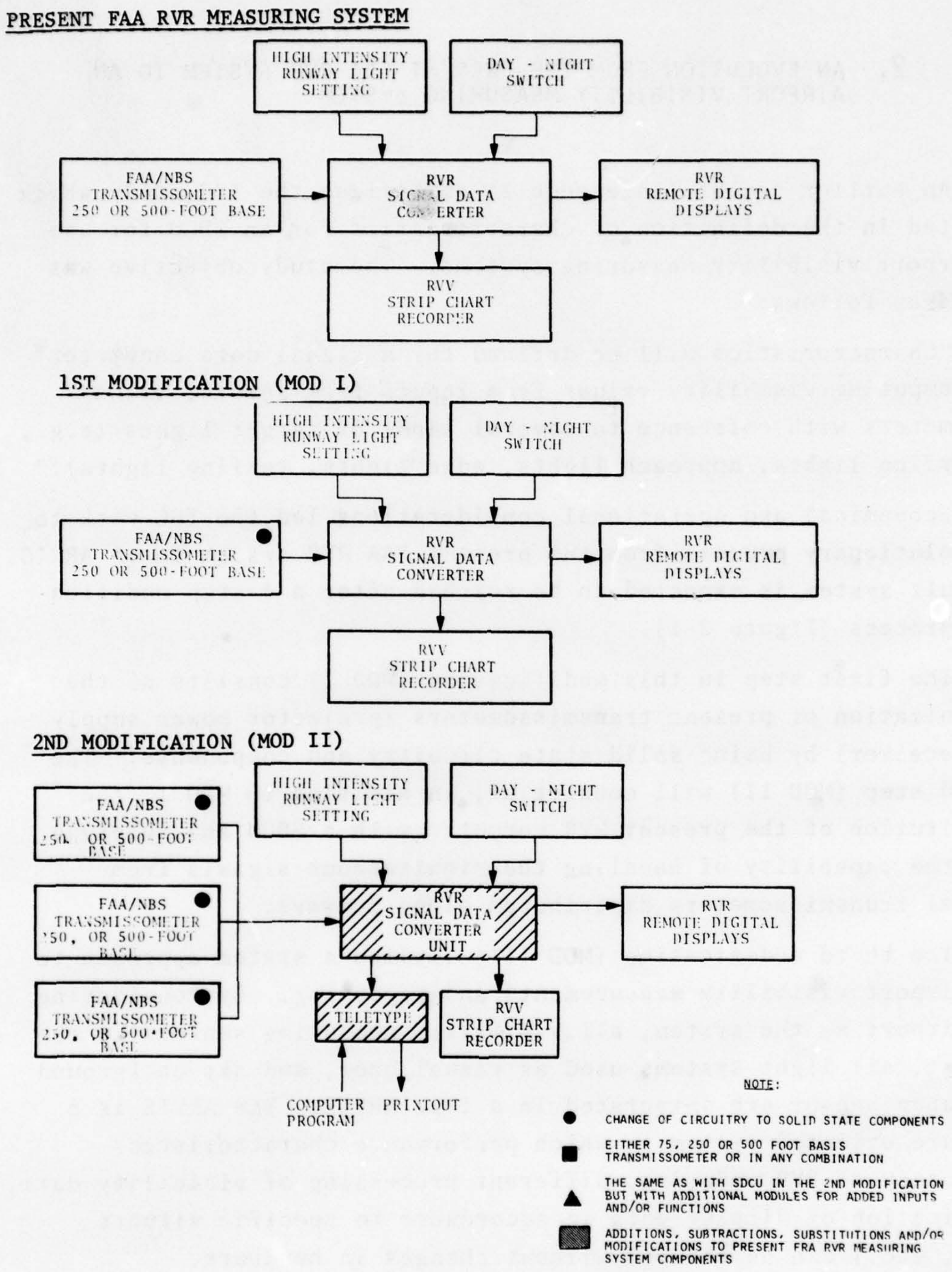
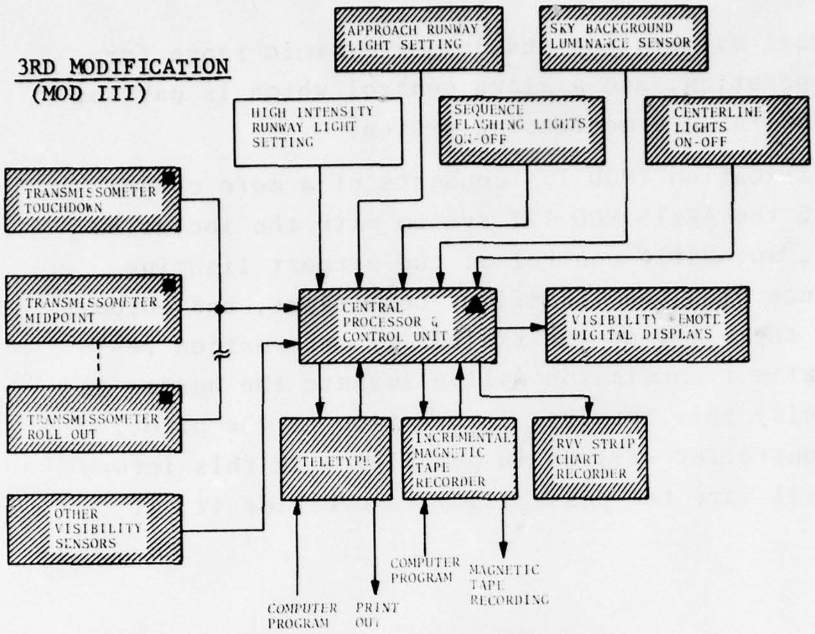


Figure 2-1. Block Diagram of an Evolution from the Present FAA RVR System to an Airport Visibility System (ARVIS)

ARVIS

3RD MODIFICATION (MOD III)



4TH MODIFICATION (MOD IV) **ARVIS**

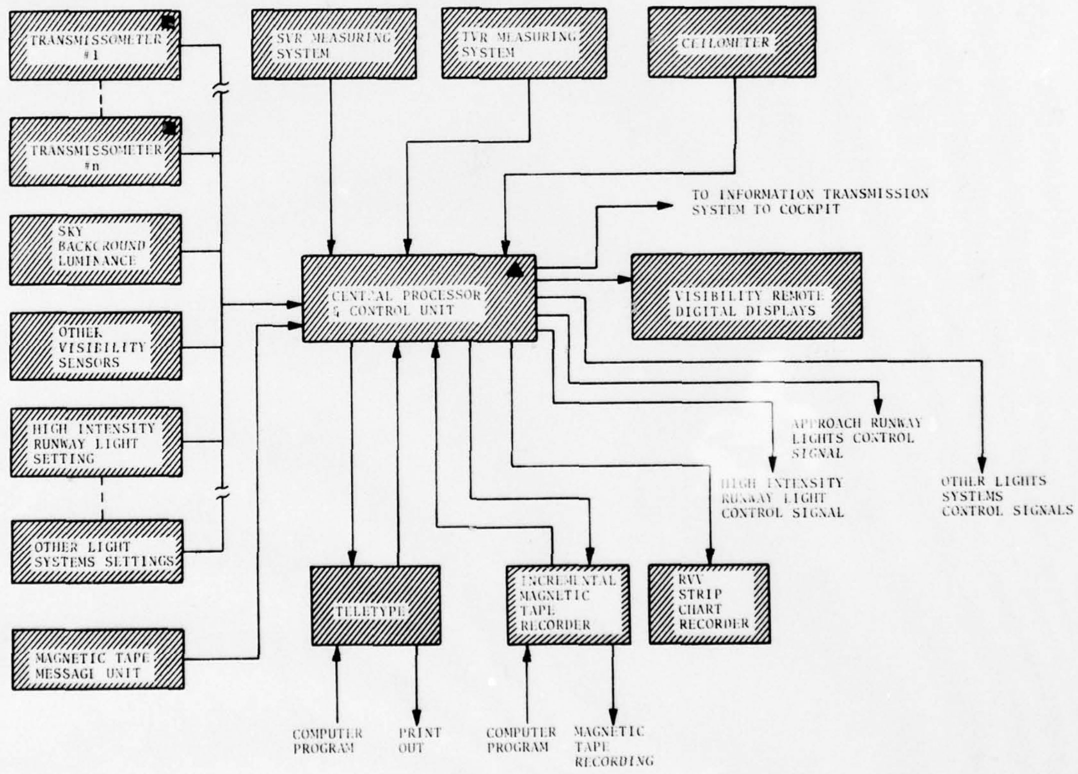


Figure 2-1. (Continued)

capability of internal calibration and larger dynamic range for CAT I, II and III operation, and a slave control which is part of the ARVIS control and failure monitoring system.

The fourth modification (MOD IV) consists of a more comprehensive expansion of the ARVIS MOD III system with the inclusion of SVR and TVR data, automatic control of the airport lighting settings in accordance with the visibility conditions, and automatic transmission to the pilot of the visibility information required. This automatic transmission will eliminate the burden on the controller to relay this terminal information to the pilot. Nevertheless, the controller will be in parallel with this information channel and will have the possibility to override it, if required.

3. PRESENT FAA SYSTEM FOR RVR MEASUREMENTS

3.1 INTRODUCTION

The present procedure used by the FAA to determine visibility at airports depends heavily on the transmissometer as an instrument to complement and, at times, replace human observers. The evolution to a comprehensive airport visibility measuring system (ARVIS), as discussed herein, will likewise center on the transmissometer as the basic sensor for gathering atmospheric transmittance.

In this section a brief description is given of the entire FAA/NBS RVR system now in use. The system includes the transmissometer, the RVR computer, the RVR remote digital displays and the RVV strip recorder and indicator.

3.2 TRANSMISSOMETER

The transmissometer, first developed by Douglas and Young at the National Bureau of Standards in 1942, measures the atmospheric transmittance over a fixed distance (usually 250 feet) with a light source and a photo-detector at opposite ends of the sampled path. First accepted for airport operations in 1952, the transmissometer serves to measure RVR or RVV along more than 270 runways. Although it has been modified by the addition of heaters, blowers, power stabilizers, etc., the basic design and operating principles of the instrument have not been changed since the first transmissometers were installed. The "Preliminary Instruction Book - Runway Visual Range (RVR) System" (Reference 3) prepared for the FAA gives a concise description of the transmissometer. The manual describes it as follows:

"The transmissometer measures atmospheric transmission by projecting a well collimated beam of light down a base line installed near the ILS glide slope transmitter building or adjacent to the touchdown area of the ILS runway, and detecting the intensity of this light in a photoelectric receiver located at the opposite end of the baseline. The receiver translates the intensity of the received light into a pulse rate by using photoelectric current generated in a vacuum photo-electric cell to charge a capacitor. When a given charge accumulates on the capacitor, a gas discharge trigger tube connected across the capacitor breaks down delivering a large impulse to the following circuitry and reducing the voltage of the capacitor to a low value equal to the extinction voltage of the gas discharge tube. This process is repeated; the time required to accumulate this charge being inversely proportional to the photocurrent and hence to the light intensity. Thus, the pulsing frequency of the circuit is linearly related to the light intensity. Through the use of an iris diaphragm in the optical system of the receiver, this pulsing rate is adjusted to 4,000 pulses per minute for 100% transmission, i.e., a clear day free of smoke, dust or haze, in the baseline path. Any such aerosol, including fog or rain, in the baseline path reduces this light intensity and hence the pulsing rate by absorbing or scattering light from the beam. Ideally, no extraneous sources of light should be permitted to enter the optical system of the receiver such that the pulsing rate would be zero in the absence of a beam from the transmitter. In any actual situation a background level of illumination exists necessitating subtracting the pulse rate measured with the transmitter source off and the pulse rate measured with the transmitter source on. This background correction must be performed from time to time to take into account changing sun position, sky brightness or weather conditions which result in spurious light scattered into the receiver. This background correction is performed manually by either switching off the projector from the indicator front panel switch and observing the recording milliammeter indication, or initiating a background check sequence by pressing a button on the signal data converter power supply and control chassis or any remote indicator chassis connected to the signal data converter control and power supply. More than one transmissometer may be used per runway as required for operation at runways approved for lower visibility operation."

3.3 RVR COMPUTER

The same manual continues: "The signal data converter computer contains the necessary time base, clock dividers and counters to permit obtaining a digital value for the transmissometer output. A separate counter is used to count and store the background count which is subtracted from the normal transmission count by entering the complement of the background count into the transmission counter prior to the 45 second period over which the transmissometer output is counted. Transmissometer output is counted for a 45 second period and then transferred into a static storage register. Three seconds later, the transmission counter is cleared, the background complement entered, and the process repeated. The value of transmissivity obtained through this count is stored such that a computation of the RVR value can take place at any time. While under normal conditions, a computation of RVR takes place only once in 48 seconds, a recomputation is initiated whenever a different RVR table is selected in response to a change in runway light setting or a change in the status of the day/night switch. These two inputs serve to select one of the six RVR tables which are plugged into the signal data converter. Systems are furnished either with class I tables pertaining to a 500 foot base line or class II tables pertaining to a 250 foot base line for the transmissometer. With a table selected, the RVR value is obtained from the table by applying clock pulses to the input of the transmissivity storage register causing it to count upward from the value of transmissivity previously stored. The number of pulses supplied to the transmissivity register is precisely equal to the capacity of the register, 2048 pulses. Thus, at the end of such a counting-compute cycle, the value stored in the transmissivity register is exactly the count which was originally stored in this register. The output of the transmissivity register is translated into a hexadecimal code and applied to the selected RVR table, an output pulse is obtained from the selected RVR table, meaning that the RVR value exceeds or is equal to the value represented by such a count. This pulse output from the RVR tables is passed through a gate and into a five bit counter. The purpose of the gate is to prevent any pulses from reaching the five bit counter until the transmissivity register has passed the overflow point; thus the number of pulses entering the five bit counter is equal to the number of RVR values which are passed between the time the transmissivity register overflows, and hence reads zero, and the time it counts up to its original stored value. Thus, the count in the five bit counter is equal to the number of the solution from zero to 21 which corresponds to the RVR value to be displayed.

The value of the RVR is transmitted to the Remote Digital Display as discussed below. During the time the SDC is not transmitting an RVR value, the receiver decoder transmits the value of runway light setting received from the runway light intensity relay box in the form of one of three frequencies with which the line is switched to common. This switching of the line is detected by the SDC and used to select the particular table required depending on the status of the day/night switch. Up to five remote indicators or computer selectors can be connected to either a signal data converter or a receiver decoder. Additional features of the signal data converter computer include two test provisions, one of which substitutes a crystal clock frequency for the transmissometer pulse output, and the other cycles the indicators through all the possible RVR values. In order to test all tables, a manual table select is available in conjunction with the first test."

3.4 RVR REMOTE DIGITAL DISPLAY

The RVR data is distributed from the RVR computer to the controllers in the control tower as numerical readouts on the Remote Digital Display Unit and then via voice link to the pilot in the aircraft. The RVR display at Logan International Airport, Boston, e.g., has the capacity to monitor two runways at a time (one transmissometer each), as selected by runway selector switches.

Readings range from 1000 to 6000 feet* and are updated approximately once a minute. RVR is given in hundreds of feet by the first two digits on the display with the third digit indicating a "+" (in excess of 6000 ft) or a "-" (less than 1000 ft).

Under conditions not requiring RVR computation, i.e., when the airport's runway lights are in intensity positions "1" or "2", an "L" appears in the third digit position of the display, indicating that the RVR computer is inoperative because it is not required.

The signals to the display unit are derived from the SDC as follows. The contents of the five bit counter holding the value of the currently-calculated RVR are decoded to yield a signal on one of the 21 lines corresponding to the 21 solutions. These lines are re-encoded into a modified indicator code which is used to operate a bank of nine relays, three for each digit and three for the symbol following the two digits. The relay contacts are appropriately wired to route the proper positive and negative voltages to the proper indicator terminals in order to display the appropriate numbers. The indicators remain quiescent until a solution is obtained at which time they are strobed for 0.75 seconds to display the new value. Simultaneous with the strobing of the indicators, the nine bit modified indicator code is transmitted in serial binary to the receiver decoder along with a parity bit for error detection. If a parity error is detected or the line is interrupted, the receiver decoder automatically forces the display to read "___ ___ E."

3.5 RVV STRIP CHART RECORDER AND INDICATOR

The pulse train from the transmissometer is also monitored by the RVV indicator. This indicator is essentially a frequency meter that converts the pulse train signal into a direct current

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*This range is for a 500-foot baseline transmissometer. For 250-foot baseline the lower RVR is 500 feet.

whose magnitude is proportional to the pulse rate. A strip-chart recorder provides a continuous record of the indicator output which is proportional to the instantaneous atmospheric transmittance.

4. PROPOSED VISIBILITY MEASURING SYSTEM

4.1 SYSTEM APPROACH

The present FAA/NBS RVR instrumentation has well served its function of gathering visibility data, computing RVR values and disseminating the information. It is clear, however, that future demands of ever increasing traffic, lowered landing minima and extensive automation of the landing process and information dissemination will require new approaches to the entire airport visibility measuring techniques. One of the approaches foreseen is the evolution of the present RVR instrumentation into a comprehensive system, increasing its accuracy, adding flexibility using a software approach, and generally improving the quality of the disseminated information as well as its output rate. The criteria to have a software oriented system precluded the consideration of analog computers as the data processing hardware. Nevertheless, for some simple instrument installations, analog computers to calculate RVR should be considered (see Appendix II). The ultimate goal is to monitor and measure the visibility in all the runways and taxiways of an airport using system concepts and state-of-the-art equipment. TSC has proposed the development of an ARVIS to satisfy this goal.

In the interest of continuity, to ensure that changes in the existing visibility instrumentation will not compromise airport safety or efficiency and to introduce changes as required, it is proposed that these be made as a series of successive modifications of the present FAA/NBS RVR system as suggested in Section 2.

The removal of units from the FAA/NBS transmissometers and the replacement and/or addition with corresponding units in the four step modification plan proposed by TSC is summarized in Table 4-1. To avoid confusion and for identification purposes, each unit of the proposed modifications has been identified with a unit number. The data given in Table 4-1 with the information supplied in figure 2-1 is self-explanatory for modifications 1 and 2.

TABLE 4-1. REMOVAL OF FAA/NBS RVR SYSTEM UNITS AND CORRESPONDING REPLACEMENTS AND/OR ADDITIONS IN PROPOSED TSC MODIFICATIONS

Modification	FAA/NBS System Unit to be Removed†	TSC Modification Unit to be Installed
I††	Pulse Generator Receiver Amplifier - Power Supply (A100-L)	*Receiver No. 10-R or No. 10-R-500
	Projector Power Supply (A300-1)	Projector Power Supply and Control No. 12-P
II	Pulse Generator Receiver Amplifier - Power Supply (A100-L)	*Receiver No. 10-R or No. 10-R-500
	Projector Power Supply (A300-1)	Projector Power Supply and Control No. 12-P
	Signal Data Converter Control and Power Supply	Minicomputer No. 24-C; I/O Interface No. 26-1; Teletype No. 28-T
	Pulse Generator Receiver Amplifier - Power Supply (A100-L)	**Receiver No. 30-R-250 or No. 30-R-75
	Projector Power Supply (A300-1)	**Projector Power Supply and Control No. 12-P
	---	**Slave Control No. 32-S
	Day/Night Switch	Sky Background Luminous Sensor No. 34-L
III (ARVIS)†††	Signal Data Converter Control and Power Supply	Minicomputer No. 24-C; I/O Interface No. 35-1; Teletype No. 28-T
	---	Incremental Digital Tape Recorder No. 36-R

TABLE 4-1. REMOVAL OF FAA/NBS RVR SYSTEM UNITS AND CORRESPONDING REPLACEMENTS AND/OR ADDITIONS IN PROPOSED TSC MODIFICATIONS (Continued)

Modification	FAA/NBS System Unit to be Removed†	TSC Modification Unit to be Installed
	---	Photometric Display No. 38-P
	Remote Display	***Remote Digital RVR Display No. 39-D
	RVV Recorder A-400	Strip Chart Recorder No. 31-R
IV (ARVIS)	Expansion of MOD III to satisfy future airport operational requirements. Hardware is not identified as yet.	

†Information on RVR system units is given in Reference 3.

††Hardware description of units and field tests described in TSC report (in preparation).

†††Hardware description in TSC report (in preparation).

*The receiver No. 10-R-250 or No. 10-R-500 can be modified to operate in a 75-foot base transmissometer by introducing minor optical modifications. (This receiver is designated No. 10-R-75.)

**Number of units depends on number of transmissometers modified.

***Number of displays as airport operations requires.

The third modification (see Figure 2-1), MOD III, a true ARVIS, will be the extension of the transmissometer network to three transmissometers per runway (at touchdown, midpoint and roll-out, and also other visibility sensors as required, for example, in the approach zone at those airports where shoreline geography creates rapidly changing conditions.) The number of transmissometers and other sensors described in MOD III implies the capability of the ARVIS, but not necessarily the actual deployment of the sensors. The ARVIS will be configured in accordance with the specific airport needs. In the MOD III, it is likely that a shorter baseline transmissometer may be introduced, and the SDCU which is part of MOD II will have to handle the outputs of this multi-transmissometer array and other visibility sensors. The SDCU input/output must be compatible with new visibility sensors. Also, it should be capable of driving new visibility remote digital displays, satisfying system control functions, and data logging.

These requirements lead to the expansion of the SDCU by additional units to the Central Processor and Control Unit (CPCU). Table 4-1 identifies the units to be removed, installed, or replaced in the FAA/NBS RVR system to reach the MOD III (ARVIS) level. Figure 4-1 gives a block diagram of a breadboard ARVIS developed at TSC.

Finally, the last modification, MOD IV, of the ARVIS will take into account all the various light targets used for visual cues, such as high intensity runway lights, taxiway lights, centerline runway lights, approach runway lights, and other lighting systems. It is expected that the CPCU will be able to use this information to calculate and display TVR and SVR. Also, there may be a need in the future to determine and display ceiling information.

The operational definition of TVR is not yet certain. Thus the method for determining TVR is not established. In the case of SVR, there may be a need for rather specialized data analysis. It is possible that the CPCU will have to be expanded in the fourth stage of modification to handle these increased data input-output demands. However, there are several minicomputers available on the market today which have expanded memories and modular architecture. It appears, too, that the very near-future will bring

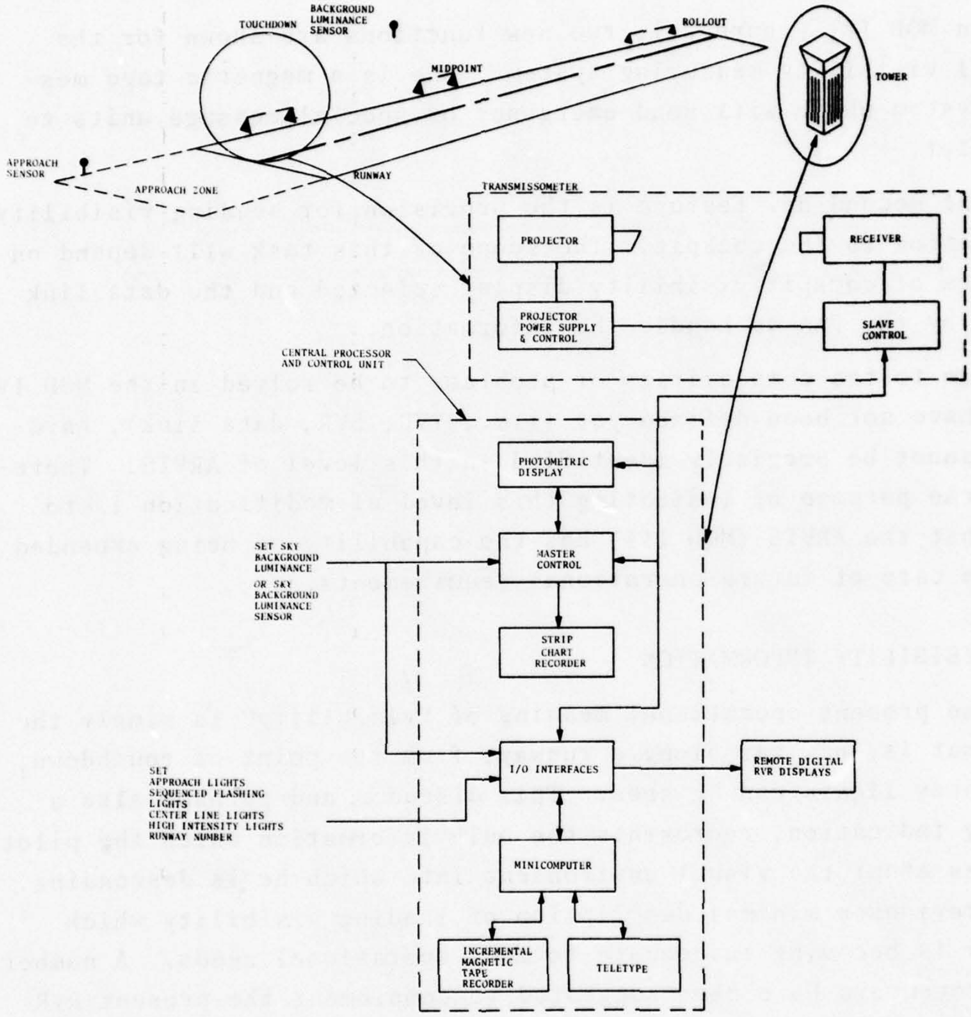

Figure 4-1. Block Diagram of the Experimental ARVIS Developed at TSC (MOD III)

minicomputers with even more capacity, more flexibility and lower prices. Therefore, it is believed that the requirements of this final stage in the evolution of the visibility measuring system can be met by modular architecture and a minimum amount of additional CPCU hardware.

In MOD IV, Figure 2-1, two new functions are shown for the overall visibility measuring system. One is a magnetic tape message system which will send emergency or special message units to the pilot.

The second new feature is the provision for sending visibility information to the cockpit. The scope of this task will depend on the form of cockpit visibility display selected and the data link chosen by the FAA to handle the information.

Due to the complexities of problems to be solved in the MOD IV which have not been defined yet (i.e., TVR, SVR, data link), hardware cannot be precisely identified in this level of ARVIS. Therefore, the purpose of indicating this level of modification is to show that the ARVIS (MOD III) has the capability of being expanded to take care of future operational requirements.

4.2 VISIBILITY INFORMATION

The present operational meaning of "visibility" is simply the RVR; that is, how far along a runway, from the point of touchdown, the runway lights can be seen. This distance, and perhaps also a ceiling indication, represents the only information which the pilot receives about the visual environment into which he is descending. This provides a minimal description of landing visibility which rapidly is becoming inadequate to meet operational needs. A number of improvements have been suggested to complement the present RVR information of describing airport visibility and to enhance the significance of visibility information for the pilot.

As has been described above, an extension of the RVR concept has been proposed in which three transmissometers are used to measure the visibility at three points along the runway. It appears that such installations will give the pilots more information in patchy fog or non-uniform weather conditions. Almost as important as the knowledge of the variation of visibility along the runway is an indication of how rapidly it is varying. This calls for a method of computation and display which brings attention to significant temporal variations in reported visibility values. Included in any attempt to handle time-varying conditions is the question of desirable up-date intervals. Whereas at present this interval is 53 seconds, the combination of larger planes and lower landing minima (Category II and III) seems to generate a need for faster updating of information. A more effective interval is about 10-12 seconds (see Reference 4).

In addition to RVR, SVR is desirable since it is a measure of how well the pilot can see the approach lights along the glide path. The SVR may well be less than the RVR in cases of inhomogeneous visibility conditions (for example, low ceiling). Since the SVR is the relevant information with regard to pilot orientation during approach, it should be included in any scheme for the modification of the visibility measuring system. The FAA is presently supporting the development of concepts and systems to measure the SVR.

TVR would provide another piece of data for the pilot and controller to use in forming a complete picture of airport visibility. As of this writing, no operational definition exists for this parameter.

Additional visibility information which must be taken into account in characterizing the overall visibility measuring system includes the prevailing visibility (which is dialed in by the controller) and the visibility of sequenced flashing lights and centerline runway lights.

4.3 VISIBILITY AND BACKGROUND INFORMATION AS CONTROL PARAMETERS FOR INTENSITY SETTING OF RUNWAY LIGHTS

At present, the high intensity runway lights are set by steps (usually three) by the controller and in accordance with the visibility and background conditions at the airport. The setting chosen by the controller can be changed on specific request of the pilot approarching for landing. The pilot communicates via voice with the controller and asks for a reduction or an increase in the intensity of the lights to improve his visibility under the prevailing conditions at that particular time. The same is true for the sequenced flashing lights (on or off).

In the MOD IV proposed visibility data flow system, we suggest the use of the visibility and background information as controlling parameters of a servo system which will control the intensity of the lights for optimum visibility under prevailing conditions. Provisions would be made to allow controller override of the servo system when unusual visibility and/or background conditions as experienced by the pilot warrant such an intervention.

5. PROGRESS ON THE VISIBILITY MEASURING SYSTEM

The Optical Devices Section at TSC has been engaged since August 1972 in the development of an experimental system conceptually defined as ARVIS (MOD III) (see Figure 2-1).

One of the design objectives of this breadboard system is that the modifications (III) shall be easily implemented in the field by means of modification units.

Development of the ARVIS system and the corresponding modification units capable of satisfying the 1st, 2nd and 3rd modification proceeded simultaneously.

The layout of the CPCU of the TSC ARVIS is shown in Figure 5-1. TSC is rapidly progressing to the point where field tests of the ARVIS could begin at NAFEC in 1976. The major developments at TSC were those relating to:

1. the modification (MOD I) of a standard FAA/NBS 250-foot baseline transmissometer as indicated in Figure 2-1.
2. the development of a new 75-foot baseline transmissometer as indicated in Figure 2-1 (MOD III configuration).
3. the development of a CPCU for the MOD III configuration, and
4. the development of an SDCU corresponding to the MOD II.

5.1 250-FOOT BASELINE TRANSMISSOMETER, MODIFICATION I

In the modification of the standard FAA/NBS 250-foot base (MOD I) transmissometer development by TSC, the original pulse generator, receiver simplifier, power supply (A100-6), and prohector power supply (A300-1) were removed from the system. The receiver housing and optics, the projector, the enclosures for the receiver amplifier and the power supply were retained. A new solid state receiver (10-R-250) mechanically interchangeable with the original pulse generator was developed. It was designed to be used in conjunction with the existing RVR signal data. The pulse rate

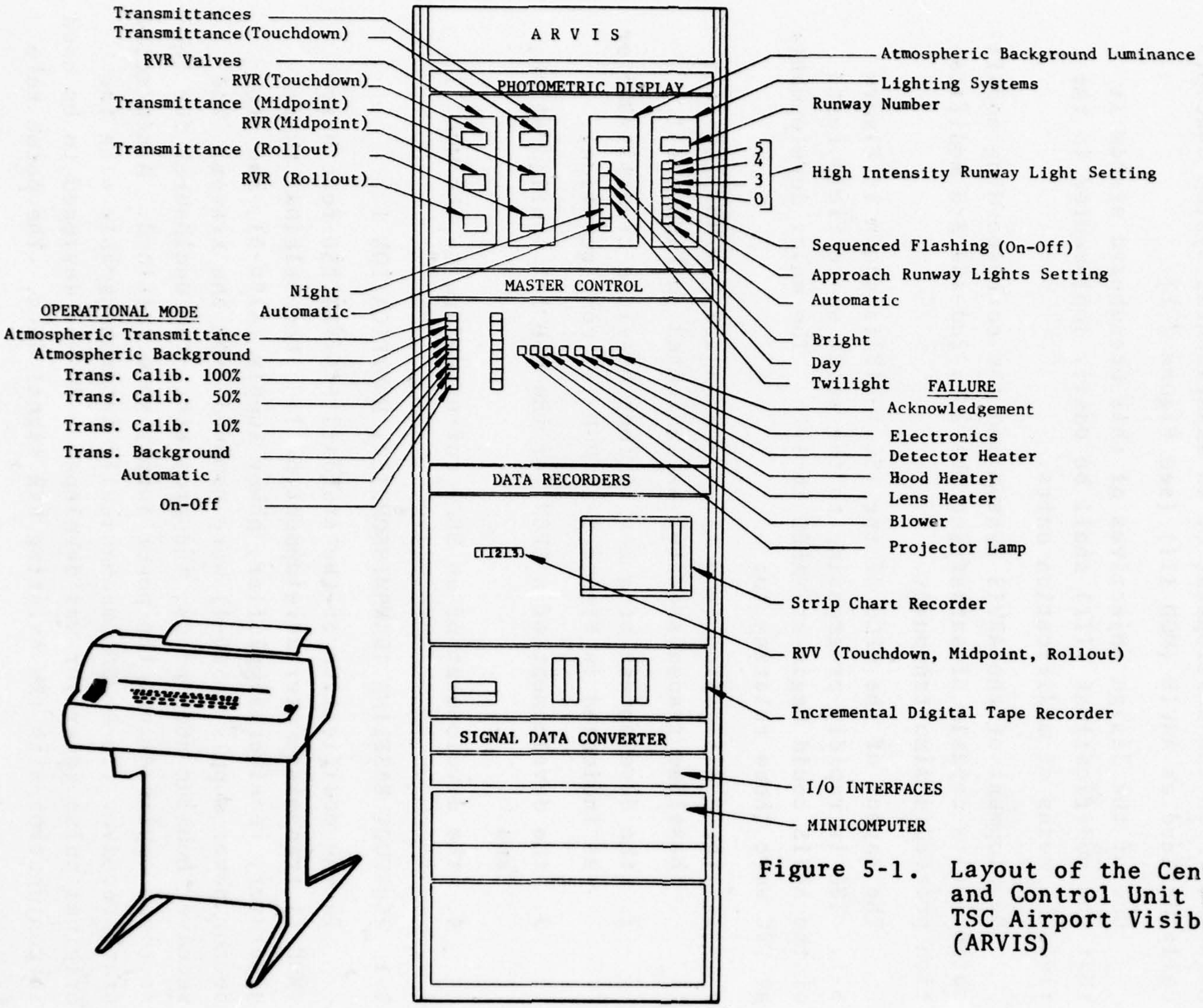

Figure 5-1. Layout of the Central Processor and Control Unit (CPCU) of the TSC Airport Visibility System (ARVIS)

of the 10-R-250 receiver is compatible with the existing RVR computer. An additional design feature of the 10-R-250 receiver is the utilization of a photopic filter ahead of the silicon detector. The filter bandpass was chosen so the detector sees a wavelength spectrum more closely matching the response of the eye of an observer by rejecting a high background level in the near infrared.

It should be indicated that the 10-R-250 can be used in either 500- or 75-foot baseline transmissometers by introducing minor optical modifications. These receivers will be respectively identified as 10-R- 500 and 10-R-75.

The original projector power supply (A300-1) has been replaced with a solid state programmable d.c. power supply and control (12-P) capable of providing stablized d.c. power to the projector lamp under wide excursions of line input voltage and frequency (105-132 V and 47 to 440 Hz) to facilitate operation under emergency power conditions. In addition, the d.c. voltage for the projector lamp is set at 5 V, increasing considerably the projector lamp life, (lamp nominal rating 6 V), thus reducing system down time and maintenance. To further increase the lifetime of the projector lamp, the 12-P power supply and control maintains a 0.5 V applied to the filament when the transmissometer background is measured. The power supply incorporates additional sensing circuits which facilitate the identification of failure modes in the projector system (power supply and/or lamp filament). The failure mode identification is basic to the MOD III system but is not active in the MOD I or II systems.

5.2 75-FOOT BASELINE TRANSMISSOMETER, MODIFICATION III

The 75-foot baseline transmissometer in the ARVIS MOD III system is reached by replacing and/or adding to the FAA/NBS 250-foot base transmissometer the following units: Receiver No. 30-R-75, Projector Power Supply and Control No. 12-B, Slave Control No. 32-S. This 75-foot base transmissometer operates in conjunction with the CPCU described in Section 5.3.

The receiver uses solid state components, has an internal optical calibration system, and failure mode detection circuitry. The No. 30-R-75 receiver measures atmospheric transmittances corresponding to the 6000 - 100 feet RVR range.

The receiver internal calibration functions are exercised periodically and provide optical detection and electronics check by sequencing through several modes: atmospheric transmittance, atmospheric background, calibration of the detector and associated electronics and transmissometer background. This is achievable by modifying the optical path viewed by the detector using a six stage optical turret assembly motor driven by the command of timing circuits in the CPCU. A miniature stablized incandescent lamp (derated to provide extended life operation in excess of 100,000 hours) is used as the receiver calibration source. Calibration is achieved at 100 percent, 50 percent, and 10 percent equivalent atmospheric transmittance through the use of neutral density filters. The receiver output calibration levels are compared with preset levels in the CPCU to activate failure mode indicators when the calibration levels fall outside a certain tolerance range indicating that corrective maintenance is required.

The other failure modes indicate malfunctions in the receiver heaters, heaters for the optics, the receiver blower, receiver power supply, projector lamp and projector power supply. The projector power supply and control No. 12-B is physically the same used in MOD I and II with a connection difference. The failure mode circuits are connected, via the slave control No. 32-S, to the CPCU. These circuits will indicate failure of the power supply and/or lamp filament.

The slave control No. 32-S receives command signals via a modem from the CPCU to exercise given functions by the receiver and/or power supply and control No. 12-B. Also the No. 32-S transmits via modem to the CPCU data failure signals and operational mode status of the 32-R-75.

5.3 CENTRAL PROCESSOR AND CONTROL UNIT (CPCU)

The FAA/NBS RVR System includes the RVR SDCU, RVV Strip Chart Recorder and Indicator in the equipment room at the control tower. The MOD I transmissometer receiver is designed to work with the forgoing RVR SDCU directly. The MOD II System configuration, however, represents a departure from the use of the current RVR SDCU. In their place is a new SDCU integrated by a minicomputer, an I/O interface and a teletype.

In the MOD III the same minicomputer and teletype of MOD II is used, but a new I/O interface (No. 35-I) is introduced. These three components integrate the MOD III SDCU and which is part of the CPCU.

The CPCU (Figure 5-2) is comprised of Master Control, Photometric Display, Data Recorders and Signal Data Converter. The operation of the CPCU is governed by mode selection switches on the Master Control. In the automatic mode an operational sequence is followed and the actual particular mode of operation is verified by the slave control.

In the automatic mode, atmospheric transmittance measurements are made over a 5 minute period followed by a 50 second atmospheric background measurement interval. This sequence is alternately repeated for 10 cycles and is then followed by a maintenance status checking sequence to assure normal transmissometer receiver operation as previously described. The latter sequence is performed during the last minute and 40 seconds of every hour. The time sequence in the CPCU can easily be varied to accommodate airport operational requirements.

The commands are transmitted to the receiver and projector over a two wire telephone line via the Slave Control Unit which is located near the receiver in the fields. The automatic sequence may be interrupted at any time to initiate a specific operational mode by depressing the appropriate Master Control Button. Once a manual mode selection is made, it remains until another mode selection is initiated. Once the automatic mode is reselected, the system continues to cycle as previously described. Should a

Figure 5-2. Photograph of the Central Processor and Control Unit (CPCU) of the TSC Airport Visibility System (ARVIS)

malfunction occur in the monitored circuits of the transmissometer, transmissometer receiver, projector lamp or projector power supply, a failure signal will be transmitted to the Master Control and a light indicator and an alarm signal will be triggered. The alarm may be turned off if the CPCU operator depresses the "failure acknowledge" button; however, the specific failure indicator will remain lighted until corrective field maintenance is implemented. The system could continue to operate but with the possibility of system performance degradation or damage.

The Photometric Display contains LED readouts arranged in columnar fashion. The second column, top to bottom, displays atmospheric transmittances for transmissometers at the touchdown, midpoint and rollout locations on the runway. These values are processed in the SDCU and displayed in the first column as RVR values at touchdown, midpoint and rollout. The third columnar display indicates the instrumented background luminance level on the runway ("automatic" switch setting) or alternatively, a value set in manually by the operator (i.e., bright, day, twilight or night switch setting). The fourth columnar display contains a LED readout indicating the specific runway monitored. A set of pushbutton switches is available for the insertion of HIRL settings 5, 4, 3, or 0 into the processor for RVR computations. In the automatic position, appropriate HIRL settings are fed automatically to the SDCU for RVR computation.

In the Data Recorders section of the CPCU there is a strip chart recorder and an incremental digital tape recorder. The strip chart recorder allows continuous atmospheric transmittance recording within .2 percent of full scale for any one of the transmissometers on the runway, selectable by means of its associated switch. Of greater significance, however, is the incorporation of a dual cassette incremental digital tape recorder which records all the available photometric data and ARVIS status. The information which is incrementally recorded every 10 seconds consists of the following: a) time in month, day, hour, minute, and second; b) runway light status, i.e., approach lights, sequenced flashing lights, background luminance input mode, background luminance; c) RVR for each of the transmissometers; d) atmospheric transmittance for each of the three transmissometers; and e) failure mode status for all three transmissometers.

A software and hardware interface is supplied to read the information on the cassette and write the information on a teletype command which activates the cassette with the computer program. The program is read from the cassette and loaded in the SDCU. The cassette recorder provides historical evidence of total system conditions at all times to facilitate critical reviews of operational integrity, especially in accident investigation.

The Power Supply Accomplishes power control, conversion and distribution to the aforementioned in the CPCU.

5.4 SIGNAL DATA CONVERTER UNIT

An experimental SDCU was developed by the Charles Stark Draper Laboratory, Inc. (Cambridge, Massachusetts) to satisfy the MOD II configuration with the capability for expansion to a MOD III. The detailed description of the SDCU is given in Appendix I.

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APPENDIX I

STUDY, DESIGN AND IMPLEMENTATION OF A SIGNAL DATA CONVERTER AND SIGNAL SIMULATOR FOR A VISIBILITY MEASURING SYSTEM

This appendix was prepared by The Charles Stark Draper Laboratory, Inc. under Contract DOT-TSC-460 with the U. S. Department of Transportation, Transportation Systems Center, Optical Devices Group.

Publication of this appendix does not constitute approval by the U. S. Department of Transportation of the findings or conclusions contained herein. It is published for the exchange and stimulation of ideas.

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SYMBOL DEFINITION AND UNITS

Symbol	Definition	Unit
b	Baselength of transmissometer	feet
B	Background luminance	candles/ft.$^{-2}$
E_t	Visual illuminance threshold	mile-candles
$f(V)$	Functional form of Allard's Law	
f_v, f_k	$f(V) = f_k = f_v$,	
	Intensity of runway lights	
I	Intensity of runway lights	candles
N	Number of bits in computer word	
N	Number of transmissometers feeding an SDCU	
N-R	Newton-Raphson method	
t_b	Atmospheric transmittance over baselength	
V	RVR, runway visual range	feet
V_a	RVR per Allard's Law	feet
V_k	RVR per Koschmeider's Law	feet
2^s	Scale factor	
β_1	Multiplying factor for Newton-Raphson method	
ε	Visual contrast threshold	
ε	Average error of the logarithm function	
α	Multiplying factor	

1. INTRODUCTION

Visibility information at U.S. airports relies upon indirect measurements based on atmospheric transmittance sensors (transmissometers) and its associated dedicated hardwired-logic controller-computer. The planned evolution(1,2) of a comprehensive integrated airport runway visibility measuring system envisages a multi-sensor system requiring a greatly expanded data acquisition, computation, logging, and display capability compared to the current FAA system.

There are many compelling motivations for using a programmable minicomputer instead of special-purpose hardwired logic. One of these motivations is the flexibility afforded by programmable systems. The software system contains the details of the application which are subject to substantial change during evolutionary development, and even from one operational facility to another. Such software systems also permit the writing of diagnostic programs that can be used for the efficient debugging of the hardware system. Because of the interdependence between the hardware and software portions of a system, the system offers a high potential for growth, and associated with this, a much longer useful life. Most real-time applications of this type are dynamic in nature. Each successful application often reveals other associated applications that are economically, technically, or administratively desirable. Programmable systems provide the flexibility to economically accommodate these dynamic system requirements.

Despite their flexibility, contemporary programmable systems often represent the lowest cost implementation. This is probably the most important motivation of all for using minicomputers. The use of general-purpose integrated components made in large quantities is the main reason for this cost advantage. Mini- and microcomputer (or microprocessor) technology is currently extremely dynamic, primarily because of advances in semiconductor component manufacturing technology. It has been predicted that entire processors will be fabricated on one chip at a cost of perhaps $10 to $20. Present-day cost is hardly much higher. This is completely within the realm of possibility today. The trend is toward increasing capability and lower costs for the main frame, central processing units, and I/O structures, and further improvement in the price/performance ratio of the future computer peripherals.

The following sections describe an investigation into some aspects important to the implementation of a minicomputer-based airport visibility measuring and control, data-logging and display system. The tasks included the following:

(1) Derivation of efficient algorithms for RVR.
(2) Accuracy versus wordlength trade-off studies.
(3) Conceptual design of software for the planned evolutionary visibility measuring systems.
(4) Design and construction of an experimental minicomputer based visibility-measuring Signal Data Converter Unit (SDCU) with simulated sensor inputs.
(5) Design and implementation of software for the experimental systems.
(6) Characterization of computer input and output data.
(7) Specification of a minicomputer portion of the SDCU and associated interface to implement the planned visibility system.

The design and construction of the experimental simulator-interface and associated software was useful in identifying special problems and served as a guide to the conceptual design of software and the specification of hardware for the planned visibility system. In addition, it demonstrates the flexibility and scope of a minicomputer-based SDCU in this application. The software developed for the experimental system may be thought of as the prototype of that required for the planned evolutionary system; it contains all submodules required for the eventual systems.

Software design and accuracy trade-off studies are extremely important tasks in the subject application. Another important task is the question of a cost-effective way of providing sufficient redundancy in the system to facilitate uninterrupted service by various measures such as the provision of complementary items, detection and appropriate action on the occurrence of anomalous and faulty system operation conditions, etc. Efficient software and thorough trade-off studies lead to a cost-effective specification for the minicomputer configuration and its associated interface. Substantial investigative effort in the above areas is justified because it is a one-time task, while multiple hardware units will be deployed when the eventual operational system is implemented.

2. DETERMINATION OF RUNWAY VISUAL RANGE (RVR)

2.1 INTRODUCTION

RVR is the maximum distance along the runway in the direction of take-off or landing at which the runway, or the specified lights, or markers delineating it, can be seen from a position above a specified point on its center line at a height corresponding to the average eye level of the pilot at touchdown. The calculation of RVR is based on the measurements of the atmospheric transmittance over a specified baselength by transmissometers located along the runway. The value of RVR that is reported is the higher value of RVR based on either the sighting of high-intensity runway lights or the sighting of the runway markers by contrast.

In this section, various aspects related to the calculation of RVR using fixed-point limited-wordlength arithmetic are considered. Allard's and Koschmieder's laws used in the calculation are described in Subsection 2.2. Algorithms for the calculation of RVR and the accuracy characteristics of the RVR calculations are considered in Subsection 2.3 and 2.4 respectively. The effect of limited-wordlength fixed-point arithmetic on the accuracy of RVR determination is considered in Subsection 2.5. Conclusions are presented in Subsection 2.6.

2.2 COMPUTATION OF RVR

The computation of RVR is based on either of the relations:

$$\varepsilon = (t_b)^{V/b}, \quad \text{(Koschmieder's Law)} \qquad (1)$$

or

$$E_t = \frac{I}{(V/5280)^2} \cdot (t_b)^{V/b}, \quad \text{(Allard's Law)} \qquad (2)$$

where

V = RVR, in feet.

b = baselength of transmissometer, in feet.

t_b = atmospheric transmittance over baselength b ($0 \leq t_b \leq 1$).

ε = visual-contrast threshold.

E_t = visual-illuminance threshold of pilot, in mile-candles.

I = intensity of runway lights, in candles.

Equation (1) represents Koschmieder's law, and is based on using contrast between an unlighted object and its background as a criterion for its visibility. Usually a contrast threshold of 5% is used for RVR calculations. Equation (2) is Allard's law for visibility of lighted sources such as runway lights. Unlike Koschmieder's law, the illuminance threshold is not constant, and depends on the background luminance, B. An empirical relationship between the two has been established by Blind Landing Experimental Unit (BLEU) and is given by

$$\log E_t = 1.3733 + 0.64 \log B \qquad (3)$$

where

B = background luminance, in candles/ft^2.

During good daytime visibility, the runway or its markings are more readily sensed by the pilot than runway lights, whereas the reverse is true during nighttime and most daytime fogs. This is reflected in the value of RVR obtained using either of the laws of Eq. (1) and Eq. (2). Thus, for RVR reporting, the higher of the two computed values is chosen.

Logarithmic transformation of Eq. (1) and Eq. (2) yields the following computationally convenient forms:

$$V = \frac{b \log \varepsilon}{\log t_b} \quad \text{(Koschmieder's Law)} \qquad (4)$$

and

$$f(V, t_b, I, E_t, b) = 0 \quad \text{(Allard's Law)} \qquad (5)$$

where

$$f(V, t_b, I, E_t, b) = \frac{1}{2} \log E_t - \frac{1}{2} \log I - \log 5280 + \log V - \frac{V}{2b} \log t_b$$

RVR for a given t_b, over a baselength b, B, and I can be obtained by choosing the higher RVR solution of Eq. (4) and Eq. (5). Koschmieder RVR can be evaluated explicitly in terms of b, ε, and t_b using Eq. (4).

On the other hand, the evaluation of Allard's RVR involves solving Eq. (5) which is a nonlinear implicit functional relation between V and data inputs b, t_b, E_t, and I. A number of iterative schemes, of varying degrees of complexity are available in the literature to solve nonlinear equations of the type f = 0. The following subsection considers some of these algorithms in the context of Eq. (5). In Subsection 2.3, we shall primarily restrict our consideration to finding efficient algorithms for computing the solution of Eq. (5).

2.3 ITERATIVE ALGORITHMS FOR ALLARD'S LAW

2.3.1 Iterative Algorithms

Figure 2-1 shows plots of f(V) for four different values of t_b and a given set of values for b, E_t, and I. The first and the second derivatives of f(V) are:

$$f'(V) = \frac{1}{V} - \frac{1}{2b} \log t_b, \tag{6}$$

$$f''(V) = -\frac{1}{V^2}. \tag{7}$$

The function f(V) is a well-behaved function of V,* possessing a unique zero, and its slope and higher derivatives do not change their sign with variation in V. These features are important in the consideration of iterative schemes to find the zero.

We restrict our consideration to single-point algorithms of the type

$$V_{i+1} = V_i - \alpha_i f(V_i) \tag{8}$$

which utilize the information from f(V) and its higher derivatives at a given point. α_i is a multiplying factor to be suitably chosen. With such algorithms, it may be easily ascertained that convergence to the zero is assured for any initial guess of V, as long as both V_i and α_i are greater than zero. On the other hand, convergence is not readily assured in case of multi-point algorithms, which utilize information about the function at more than one point.

---

*Except near the singularity at V = 0, where the value of f(V) tends to minus infinity. By posting a lower limit on the range of variation of V, the singularity and the attendant problems are easily avoided in numerical computations. The limit can be as low as 1.

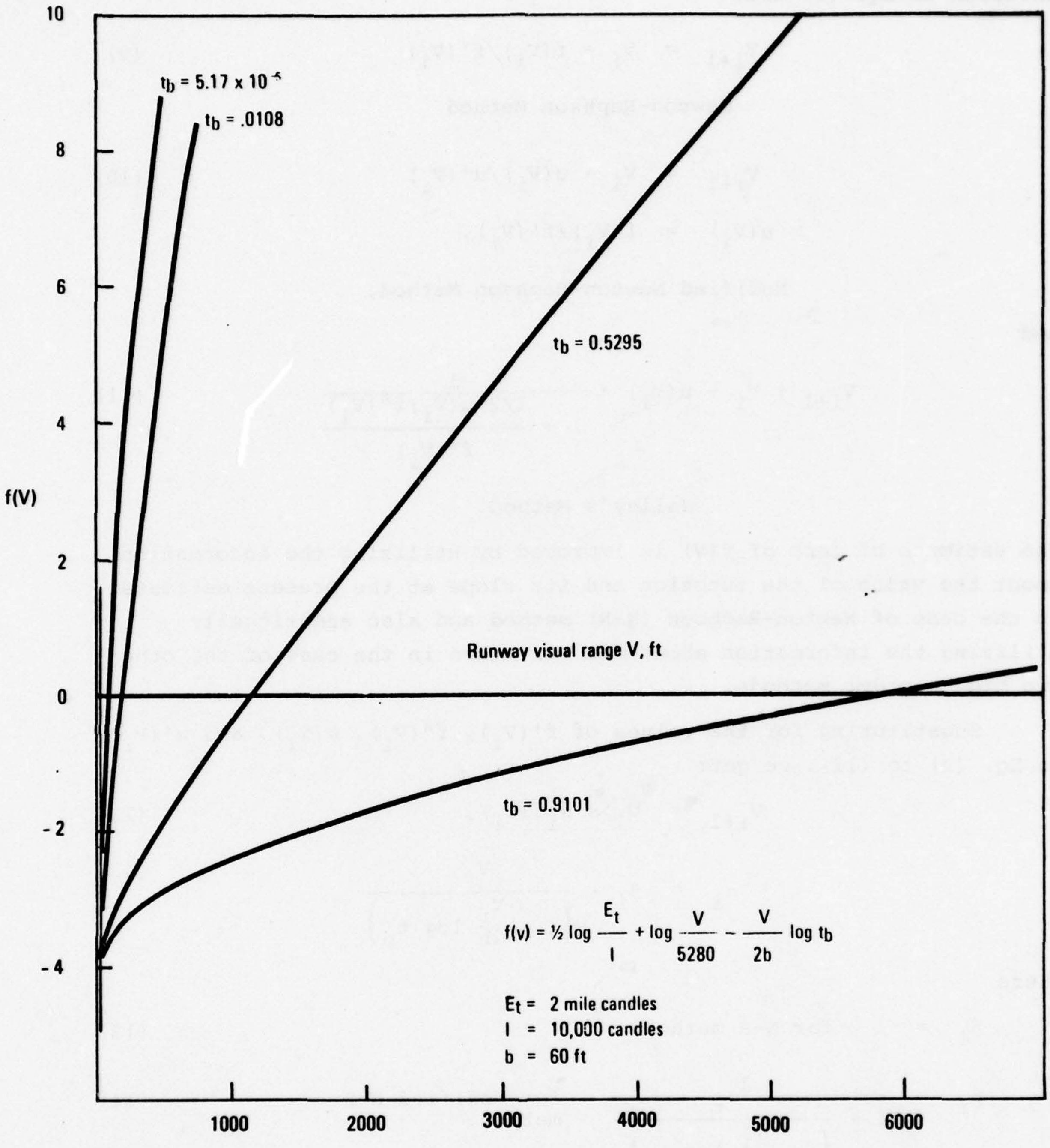

Figure 2-1. Plot of f(V). Allard's law satisfies when f(V) = 0. By posting a lower limit on the range of variation of V, the singularity and the attendant problems are easily avoided in numerical computations. The limit can be as low as 1.

Three single-point iterative algorithms considered here for the solution of Eq. (5) are:*

$$V_{i+1} = V_i - f(V_i)/f'(V_i) \tag{9}$$

Newton-Raphson Method

$$V_{i+1} = V_i - u(V_i)/u'(V_i) \tag{10}$$

$$u(V_i) = f(V_i)/f'(V_i),$$

Modified Newton-Raphson Method,

and

$$V_{i+1} + V_i - u(V_i) \cdot \frac{1}{1 - \dfrac{1/2\, u(V_i) f''(V_i)}{f'(V_i)}} \tag{11}$$

Halley's Method.

The estimate of zero of f(V) is improved by utilizing the information about the value of the function and its slope at the present estimate in the case of Newton-Raphson (N-R) method and also additionally utilizing the information about the curvature in the case of the other two higher-order methods.

Substituting for the values of $f'(V_i)$, $f''(V_i)$, $u(V_i)$, and $u'(V_i)$ in Eq. (9) to (11), we get:

$$V_{i+1} = V_i - \alpha_i f(V_i), \tag{12}$$

$$\alpha_i = \beta_i \cdot \frac{V_i}{\left(1 - \frac{V_i}{2b} \log t_b\right)}$$

where

$$\beta_i = 1 \quad \text{for N-R method,} \tag{13}$$

$$\beta_i = \frac{1}{1 + \dfrac{f}{\left(1 - \frac{V_i}{2b} \log t_b\right)^2}} \quad \text{for modified N-R method,} \tag{14}$$

---

*Further details on the derivation and the performance of these algorithms are given in Appendix A.

$$\beta_i = \frac{1}{1 + 1/2 \, \dfrac{f}{\left(1 - \dfrac{V_i}{2b} \log t_b\right)^2}} \quad \text{for Halley's method.} \tag{15}$$

The multiplying factor β for modified N-R and Halley's methods takes into account the curvature of the function.

For assured convergence, both α_i and V_i should be greater than zero. Further restrictions on the magnitude of β_i and V_i need to be imposed as shown below to meet the above requirements.

$$V_i > 0 \quad \text{for N-R method} \tag{16}$$

$$\left.\begin{array}{l} V_i > 0, \\ \beta_i > \gamma > 0 \end{array}\right\} \text{for modified N-R method} \tag{17}$$

$$\left.\begin{array}{l} V_i > 0, \\ \beta_i > \gamma > 0 \end{array}\right\} \text{for Halley's method} \tag{18}$$

The limit γ is to be suitably chosen in Eq. (17) and Eq. (18). A further restriction on the maximum value of V_i may be required to prevent overflow during the fixed-point computations.

2.3.2 Selection of an Algorithm

The order of convergence (i.e., how fast the convergence is) could form the basis of choice for the selection of an iterative algorithm. However, it is more realistic and meaningful to compare the computational efficiency, which measures the total amount of numerical computations that need to be done to arrive at a given accuracy in finding the zero. The total amount of computations depends upon the initial estimate, numerical computations (sometimes termed as cost) per iteration and total number of iterations necessary to arrive at a given accuracy in finding the zero. The numerical costs associated with the three algorithms are of the same order, since the increase in the computations involved with modified N-R and Halley's methods is very small. The total number of iterations required depends on the initial estimate, the order of accuracy required, the order of convergence of the algorithm, and the nature of f(V). It may seem from Figure 2-1 and Eq. (7) that f(V) is nearly linear except at low values of V. Thus, it may be expected that the performance of the three algorithms would be similar.

Table 2-1 shows the results of a convergence study of different algorithms carried out on a digital computer.* RVR is computed for eight different values of transmittance, t_b, over a baselength of 60 feet. E_t = 2 mile-candles and runway high-intensity light of 10,000 candles. The starting guess for all iterative schemes is 1000 feet. Table 2-1 lists the values of RVR V(I) at different stages of iteration, I, for four different algorithms. The table includes Method 2, which is a variation of the two higher-order methods described in Subsection 2.3.1. Appendix A includes the description, including the derivation of Method 2. The exit criterion employed for this study is given by $|\Delta V_i| \leq 10^{-4}$. For the modified N-R method and Halley's method, $\gamma = 0.5$ was employed. The following observations are made with respect to the above study:

(1) For low-transmittance values (low RVR) the performance of all four methods is nearly similar, with that of the N-R method slightly better than those of the other three methods.

(2) For high transmittance values (high RVR) the three methods using the second derivative perform slightly better than the N-R method. As expected, for initial guesses far off from the actual RVR, the next iterates are much closer to the actual RVR for these methods than for the N-R method. The performance of the modified N-R method is slightly superior to the other three methods.

(3) The selection from amongst the four methods would primarily depend upon the level of accuracy specified. For example, for the high accuracy of the order of 10^{-4} used for study, the number of iterations needed to reach this high accuracy are roughly the same for all methods. However, for low accuracy requirements, the number of iterations for the three methods using the second derivative are slightly less than that for N-R method. However, for these higher-order methods, this slight advantage in the total number of iterations is offset by the small increase in the numerical cost per iteration.

One of the conclusions that emerges from the above observations is that there is not much to be gained by way of convergence and computational efficiency in going from the simpler N-R method to the higher-order methods such as modified N-R or Halley's methods.

---

*Because of the nature of the study, floating-point arithmetic was used.

TABLE 2-1. COMPUTER PRINTOUT SHOWING CONVERGENCE FOR DIFFERENT ALGORITHMS TO COMPUTE RVR

```
ET=       2.000000
INT=20000.000000
BASE LENGTH=     60.000000


TB=       .012860

I                                V(I)
                 N-R              NO. 2          MOD. N-R           HALLEY
1         222.162907       240.216702       256.668720       239.807174
2         216.016616       218.196882       220.516118       218.147888
3         215.257193       215.535975       215.840268       215.529743
4         215.159844       215.195734       215.235044       215.194932
5         215.147308       215.151932       215.157000       215.151829
6            .000000       215.146289       215.146942       215.146275

TB=       .213200

I                                V(I)
                 N-R              NO. 2          MOD. N-R           HALLEY
1         564.596618       578.972733       591.567784       578.513235
2         539.185700       541.228057       543.312205       541.165753
3         535.828154       536.117468       536.419778       536.108730
4         535.357059       535.398037       535.441002       535.396801
5         535.290423       535.296227       535.302315       535.296052
6         535.280986       535.281808       535.282671       535.281784

TB=       .398990

I                                V(I)
                 N-R              NO. 2          MOD. N-R           HALLEY
1         860.661609       862.905975       865.010251       862.870397
2         844.132236       844.499905       844.865831       844.494595
3         841.741202       841.796673       841.852384       841.795885
4         841.386556       841.394835       841.403160       841.394717
5         841.333761       841.334995       841.336236       841.334977

TB=       .483940

I                                V(I)
                 N-R              NO. 2          MOD. N-R           HALLEY
1        1026.441559      1026.537949      1026.635754      1026.538301
2        1030.636902      1030.653989      1030.671118      1030.654045
3        1031.280717      1031.283379      1031.286042      1031.283387
4        1031.379000      1031.379407      1031.379815      1031.379409
```

TABLE 2-1. COMPUTER PRINTOUT SHOWING CONVERGENCE FOR DIFFERENT ALGORITHMS TO COMPUTE RVR (Cont.)

```
   IS=     .647300

   I                               V(I)
                 N-R             NB. 2          MOD. N-R            HALLEY
   1     1446.177337      1484.845741       1539.729774       1488.514974
   2     1572.393805      1580.804513       1590.341875       1581.443206
   3     1595.440270      1596.860675       1598.413128       1596.964552
   4     1599.229274      1599.459349       1599.709446       1599.476081
   5     1599.840572      1599.877610       1599.917833       1599.880300
   6     1599.938913      1599.944869       1599.951336       1599.945301

   IS=     .723100

   I                               V(I)
                 N-R             NB. 2          MOD. N-R            HALLEY
   1     1736.756079      1863.377142       2122.634657       1889.654758
   2     2075.849330      2057.978717       2103.270138       2062.844035
   3     2086.682716      2092.443683       2100.043380       2093.267605
   4     2097.269739      2098.240330       2099.506426       2098.377803
   5     2099.044613      2099.206420       2099.417095       2099.229301
   6     2099.340258      2099.367185           .000000       2099.370992
   7     2099.329452          .000000           .000000           .000000

   IS=     .912600

   I                               V(I)
                 N-R             NB. 2          MOD. N-R            HALLEY
   1     2796.578096      3695.317145       4593.756193       4593.756193
   2     4757.852330      5390.261349       5669.248529       5621.516205
   3     5687.057781      5796.113044       5853.836383       5843.282148
   4     5842.934089      5877.747026       5888.972402       5886.298316
   5     5886.774012      5893.541591       5895.698836       5895.299475
   6     5895.273726      5896.573993       5896.987621       5896.911020
   7     5896.976003      5897.155316       5897.234590       5897.219908
   8     5897.213344          .000000           .000000           .000000

   IS=     .833500

   I                               V(I)
                 N-R             NB. 2          MOD. N-R            HALLEY
   1     2263.287816      2745.345159       3526.495632       3050.753806
   2     3099.308563      3272.191304       3471.192166       3333.785640
   3     3340.013001      3275.637115       3402.448929       3386.848792
   4     3387.852656      3394.357721       3399.123328       3396.354624
   5     3396.931411      3397.688557       3398.533723       3398.042831
   6     3398.074076      3398.279377       3398.429206       3398.342186
   7     3398.347722      3398.384119           .000000           .000000
```

2.3.3 Steps for an Algorithm to Compute RVR

An iterative algorithm based on Eq. (12) to (18) is described in the following. The algorithm computes RVR based on E_t, I, and t_b.

The algorithm consists of the following steps:

(1) For data inputs E_t, I, and t_b, calculate log E_t, log I, log t_b, and f_k where $f_k = 1/2(\log E_t - \log I) - \log 5280$.

(2) Consider an initial guess V_0 for RVR which may be based upon the previous or old RVR calculated, or may be a fixed quantity.

(3) Calculate

$$f_v = \log V_i - \frac{V_i \log t_b}{2b}$$

and

$$f(V_i) = f_k + f_v.$$

(4) Calculate

$$\Delta V_i = \beta_i \frac{V_i f(V_i)}{1 - \frac{V_i}{2b} \log t_b},$$

with

$$\beta_i = 1 \quad \text{for N-R method,}$$

$$\left.\begin{array}{l} \beta_i = \dfrac{1}{1 + X} \\ X \geq \gamma - 1 \end{array}\right\} \text{for modified N-R method,}$$

$$\left.\begin{array}{l} \beta_i = \dfrac{1}{1 + \frac{X}{2}} \\ \frac{X}{2} \geq \gamma - 1 \end{array}\right\} \text{for Halley's method,}$$

where

$$X = \frac{f(V_i)}{\left(1 - \frac{V_i}{2b} \log t_b\right)^2}$$

and γ is a given positive number.

(5) Calculate

$$V_{i+1} = V_i - \Delta V_i,$$

subject to the restrictions,

$$V_{min} \leq V_{i+1} \leq V_{max}$$

where V_{min} and V_{max} are given.

(6) Check if a given exit* criterion is satisfied. If not, go to Step (3).

(7) The RVR so calculated is Allard's RVR, say V_A. Calculate V_K, Koschmieder RVR from

$$V_K = \frac{b \log \varepsilon}{\text{lot } t_b},$$

and where

$$\varepsilon = 0.05.$$

For RVR reporting, choose the higher of the two values, V_A and V_K.

2.4 RVR COMPUTATION ACCURACY

Accuracy characteristics of RVR computations are considered in Subsections 2.4.1 through 2.4.3. Error in the determination of RVR may arise due to error measurement of input parameters E_t, I, and t_b, and due to truncation errors in the arithmetic involved in the calculation of RVR from Allard's law and Koschmieder's law.

2.4.1 Allard's Law

Let V represent the RVR for a set of input data E_t, I, and t_b. Consider a change in data inputs to $E_t + dE_t$, $I + dI$, and $t_b + dt_b$. Corresponding change dV, in the value of RVR, is given by

$$f(V + dV, E_t + dE_t, I + dI, t_b + dt_b) - f(V, E_t, I, t_b) = 0$$

or

---

*Since exact RVR is not known, the exit criterion may be based on how close to zero either $f(V_i)$ or ΔV_i is satisfied.

$$\frac{1}{2}\log\left(1+\frac{dE_t}{E_t}\right)-\frac{1}{2}\log\left(1+\frac{dI}{I}\right)+\log\left(1+\frac{dV}{V}\right)$$

$$-\frac{V}{2b}\log\left(1+\frac{dt_b}{t_b}\right)-\frac{dV}{2b}\log\left(t_b+dt_b\right)=0.$$

The change in RVR can be explicitly evaluated from the above expression if the percentage changes (or errors) in the nominal values of E_t, I, and t_b are small. Thus, we get:

$$\frac{dV}{V}=\frac{2\,\frac{1}{V}\left(\frac{dI}{I}-\frac{dE_t}{E}\right)+\frac{1}{b}\cdot\frac{dt_b}{t_b}}{f'(V)} \tag{19}$$

where

$$f'(V) = \frac{1}{V}-\frac{1}{2b}\log t_b$$

Equation (19) relates the effect of errors in I, E_t, and t_b on the determination of RVR from Allard's law. The following observations may be made with respect to Eq. (19).

(1) The percentage error in RVR is inversely proportional to $f'(V)$, the slope of $f(V)$ at its zero. It may be seen *from Figure 2-1 that the slope is larger at higher values* of RVR. Thus, a given percentage in the input data, E_t, I, and t_b leads to a larger percentage change in RVR *during high RVR conditions and a smaller change during* low RVR conditions.

(2) Larger percentage errors can be tolerated for I or E_t than for t_b because of the weighting factors V and b involved in each case. The effect of errors in I or E_t becomes unimportant during low-visibility conditions.

(3) For large t_b (or large V),

$$\frac{dV}{V}\simeq-\frac{d(\log t_b)}{\log t_b} \tag{20}$$

2.4.2 Koschmieder's Law

By differentiating Eq. (3) we obtain the following relationship between dV and t_b.

$$\frac{dV}{V} = - \frac{d(\log t_b)}{\log t_b} \tag{21}$$

It may be noted that the effect of errors in t_b is similar for both Koschmieder's and Allard's laws during good visibility conditions.

2.4.3 Effect of Truncation Error

Error in the computation of a logarithm function is the major source of error, due to loss of significance in the calculation of RVR. Equations (19) and (21) also may be utilized to predict the effect of truncation error in the computation of the logarithm of V and the input values E_t, I, and t_b. Thus, for Allard's law we get:

$$\frac{dV}{V} = \frac{\frac{1}{2V}\left[d(\log I) - d(\log E_t)\right] + \frac{1}{b}\, d(\log t_b)}{f'(V)}$$

The effect of wordlength and truncation on the accuracy of RVR determination is considered in Subsection 2.5.

2.5 FIXED-POINT COMPUTATION OF RVR

In fixed-point calculations suitable scaling of numbers becomes necessary to avoid the overflow or loss of significance likely to result during the arithmetical operations on numbers whose magnitudes may vary over a wide range. The numbers can be scaled up or down by the use of a suitable multiplying factor chosen to satisfy the significance requirements needed in the arithmetical operations.

The most involved calculations in the computation of RVR arise in the calculation of logarithms of various quantities such as E_t, I, t_b, and V. It has been shown in Subsection 2.4 how the accuracy in the determination of RVR is affected by the loss of significance due to truncation in the calculation of logarithm of input quantities E_t, I, and t_b. The loss of accuracy can be avoided or kept to a minimum provided unlimited wordlength is available for the fixed-point arithmetic and a suitable scaling is adopted. However, in case of limited-wordlength arithmetic, the magnitude of the scale factor and consequently the accuracy attainable are governed by the overflow problems associated with the limited wordlength.

The rest of the section is devoted to the consideration of:

(1) Scaling and its effect on the accuracy of RVR determination.

(2) Overflow problems associated with scaling and the measures to avoid overflow during RVR computations.

(3) Order of accuracy attainable for a given wordlength.

A limited-wordlength integer arithmetic is assumed in the discussions that follow.

2.5.1 Scaling

Consider a scale factor of 2^s associated with the computation of RVR laws. By multiplying Eq. (5) by 2^s we have:

$$2^s f(V) = \frac{1}{2} 2^s \log E_t - \frac{1}{2} 2^s \log I - 2^s \log 5280 + 2^s \log V - \frac{V}{2b} \cdot 2^s \log t_b \qquad (22)$$

The operations of addition, subtraction, multiplication, and division are carried out in single-precision-integer arithmetic in the evaluation of $2^s f(V)$.* The evaluation of the logarithm of E_t, I, t_b, and V is further assumed to be handled by a software routine that employs an efficient high-accuracy algorithm employing integer arithmetic. Appendix B describes such an algorithm for calculating the logarithm of an integer. It is also shown that the order of accuracy associated with this algorithm is approximately $2^{-(N-5)}$, where N = length of the computer word that represents a single-precision number, including a bit for the sign. Thus, the error in the scaled-integer representation of a logarithm of a number, such as $2^s \log I$, is of the order of 2^{-s} for $s \leq N - 5$, and represents the dominant source of error in the RVR calculations.

We shall consider the error introduced in the determination of RVR due to the truncation in the calculation of logarithm. Let V represent the correct RVR for a set of input data E_t, I, and t_b. The change in the value of f(V) due to the error in the logarithm of this set of data is given by

---

*An operation, such as $I \cdot J/K$, involving multiplication and division among single-precision numbers may be considered a single operation, provided the single-precision-integer arithmetic associated with the computer provides a double-precision product of I and J, which in turn is used as a double-precision dividend for the divide operation by K. Most of the computers have such a hardware or software capability associated with the single-precision multiply and divide operations.

$$2^s df = \frac{1}{2}\Delta(2^s \log E_t) - \frac{1}{2}\Delta(2^s \log I) - \frac{V}{2b}\Delta(2^s \log t_b), \qquad (23)$$

where Δ represents the truncation error.

If $2^s df \geq 1$, this leads to an error in the RVR determination. The error, dV in the value determined by RVR algorithms due to this error in df can be estimated to first order in dV from the relation:

$$dV\left(\frac{2^s}{2V} - \frac{2^s}{2b} \log t_b\right) = -2^s df \pm 1. \qquad (24)$$

The right-hand side of Eq. (24) represents the change in f(V) due to dV necessary to cancel the effect of truncation error in the calculation of the logarithm of E_t, I, and t_b. From Eq. (23) and Eq. (24) we obtain:

$$dV = \frac{1 + \frac{V}{2b}(2^s \log t_b) + \frac{1}{2}(2^s \log E_t) - \frac{1}{2}(2^s \log I)}{\frac{2^s}{V} - \frac{2^s}{2b} \log t_b} \qquad (25)$$

Now, the magnitudes of $2^s \log t_b$, $2^s \log E_t$, and $2^s \log I$ are all less than 1. Thus, for $V > 2b$,

$$dV \simeq \frac{V}{2bf'(V)} \cdot \frac{1}{2^s} \qquad (26)$$

Equation (26) represents the order of accuracy associated with fixed-point calculations for determining RVR from Allard's law. The order of accuracy is seen to depend upon the order of significance retained in the logarithmic representation of numbers and upon the value of the atmospheric transmittance, which in turn determines the slope of the function and the magnitude of RVR. For $V \gg 2b$, i.e., large t_b,

$$dV = \frac{V \cdot \frac{1}{2^s}}{\log t_b} \qquad (27)$$

Table 2-2 gives, for four different transmittances, both the predicted as well as the actual RVR errors for different scale factors in the calculation of RVR from Allard's law. The related RVR parameters are E_t = 2 mile-candles, I = 10,000 candles, and b = 60 feet. The numerical computations for actual RVR errors were carried out for a 16-bit-wordlength integer arithmetic. The actual and predicted error

TABLE 2-2. PREDICTED AND ACTUAL ERROR IN RVR, DUE TO SCALING IN COMPUTATION OF RVR FROM ALLARD'S LAW, USING FIXED-POINT CALCULATIONS, FOR FOUR DIFFERENT TRANSMITTANCES (E_t = 2 MILE-CANDLES, I = 10,000 CANDLES, b = 60 FEET)

Scale Factor	t_b = 0.0108;	V = 200 ft	t_b = 0.341;	V = 700 ft	t_b = 0.53;	V = 1100 ft	t_b = 0.91;	V = 5400 ft
	ΔV_{pred} ft	ΔV_{act} ft	ΔV_{pred} ft	ΔV_{act} ft	ΔV_{pred} ft	ΔV_{act} ft	ΔV_{pred} ft	ΔV_{act} ft
32	1	2	17	52	44	162	1340	1389
64	0	1	8	23	22	35	670	1312
128	0	0	4	8	11	7	335	234
256	0	0	2	2	5	8	169	196
1024	0	0	1	3	2	8	83	13

values seem to be roughly of the same order (bearing in mind that Eq. (26) gives only the order of errors expected).

The loss of significance and, consequently, the error in RVR determination can be held down by using a scale factor as large as is feasible.

2.5.2 Overflow Problems

The upper limit on the magnitude of the scale factor is governed by overflow problems associated with large numbers for a limited-wordlength arithmetic.

Table 2-3 shows the magnitude of overflow problems associated with the computation of RVR. It shows the data inputs and various quantities that enter into the computation during a Newton-Raphson algorithm for Allard's law. Also shown are the associated lower and upper limits within which the values of these quantities would lie, assuming a scale factor of 1 for the quantities involving logarithms. The quantities $V \log t_b/2b$ and $f(V)$ may attain a value as high as $2^s \cdot 600$, assuming that scaling is employed for calculations. Such high values may be obtained during an iteration at low values of t_b coupled with high values of V (see Figure 2-1). High values of V may result, due to a poor initial guess for V, or may be obtained during iterations if a higher-order algorithm, such as modified Newton-Raphson or Halley's algorithm, is used with a low value assigned to γ.

To prevent overflow, we require $2^s 600 < 2^{N-1}$, where N is equal to the number of bits in a wordlength used for a signed binary representation of a number. This requires $s < N - 10$. Thus, for a 16-bit wordlength, s should be less than 6. It may be seen from Table 2-2 that the accuracy in RVR associated with $s = 32$ is poor at high values of t_b. For example, at $t_b = 0.91$ and $V = 5400$ feet, the error in RVR is about 24%, which is a high value indeed. However, accuracy may be improved by using larger scale factors provided proper precautions are taken such that higher values of V are avoided during intermediate iterations at low values of t_b. Otherwise, it may become necessary to use larger-wordlength arithmetic or floating-point arithmetic.

A few observations on the question of overflow and convergence are considered below, before going into the consideration of measures to avoid the overflow problems.

TABLE 2-3. RANGE OF QUANTITIES INVOLVED IN CALCULATING RVR FROM ALLARD'S LAW USING NEWTON-RAPHSON METHOD

Quantity	Range	Quantity	Range	Quantity	Range
Runway visual range, V, ft	1 to 6000	log V	0 to 3.8	$f_k = 1/2 \log \frac{E_t}{I} - \log 5280$	-5.72 to -3.37
Illumination threshold, E_t, mile-candles	2 to 2000	$\log E_t$	0.3 to 3.3	$f_k + \log V$	-5.72 to 0.43
Intensity runway light, I, candles	400 to 20000	log I	2.6 to 4.3	$f(V) = f_K + \log V - \frac{V}{2b} \log t_b$	-5.72 to 600
Atmospheric transmittance, t_b	10^{-5} to 1	$\log t_b$	-5 to 0	$\frac{V}{1 - \frac{V}{2b} \log t_b}$	1 to 10
Baseline, b, ft	50 to 750	$- \frac{V}{2b} \log t_b$	0 to 600	$\Delta V_i = \frac{Vf(V)}{1 - \frac{V}{2b} \log t_b}$	-5.72 to 6000

(1) At low t_b and high RVR

$$f(V) \simeq V \log t_b/2b = \alpha,$$

and

$$f'(V) \simeq \log t_b/2b = \alpha/v,$$

thus, for a Newton-Raphson method

$$\Delta V_i \simeq -V_i, \text{ and } V_{i+1} \simeq 0.$$

(2) Convergence to a correct value of RVR is assured using an iteration scheme of the type:

$$V_{i+1} = V_i - \varepsilon_i \operatorname{sign}(f(V_i)), \; \varepsilon_i > 0.$$

(3) To prevent overflow, we require:

$$2^s f(V) < 2^{N-1}, \; s \leq N - 5.$$

This in turn implies:

$$-2^s V \log t_b/2b < 2^{N-1} - 2^s(f_k + \log V).$$

From Table 2-3:

$$2^s(f_k + \log V) < 2^s \times 0.43 < 2^{s-1}.$$

Thus, to prevent overflow, at all stages of iteration we require

$$-2^s V \log t_b$$

to be less than K, where

$$K = 2^{N-1} - 2^{s-1}.$$

2.5.3 Modification to RVR Algorithm

The above discussion suggests the following modifications to the RVR algorithm for Allard's law described in Subsection 2.3:

(1) Set $-V \cdot 2^s \log t_b/2b = K$, if $-V \cdot 2^s \log t_b/2b > K$, with

$$K = 2^{N-1} - 2^{s-1}$$

and

$$s \leq N - 5.$$

(2) Set $\beta = \gamma$ if $\beta < \gamma$, $\gamma > 0$

for modified Newton-Raphson and Halley's algorithms. The value for γ is to be appropriately selected to assure convergence without any overflow problems that may arise at a low value of γ.

It is easy to ascertain, in the light of earlier observations, that the convergence of the modified RVR algorithm for Allard's law is assured without any overflow problems.

2.5.4 Wordlength and RVR Accuracy

With the modifications incorporated into an RVR algorithm as discussed in Subsection 2.5.3, higher accuracies in RVR can be achieved for a given wordlength by using larger scale factors.

Figures 2-2 to 2-4 show the effect of limited wordlength on the accuracy of RVR calculated from Allard's law using fixed-point arithmetic and a scale factor of 2^s with $s = N - 6$. Figures 2-2 and 2-3 correspond to nighttime conditions (E_t = 2 mile-candles) whereas Figure 2-4 corresponds to bright daytime operations (E_t = 2600 mile-candles). The runway light intensity, I, is equal to 10,000 candles and the transmissometer baselength is equal to 60 feet.

Figures 2-3 and 2-4 show the percentage errors in transmissivity that arise due to truncation in the calculation of its logarithm employing 12-, 14-, and 16-bit-wordlength arithmetic.

Besides the errors due to truncation during RVR calculations, additional errors arise in transmittance during its measurement and transmission. The accuracy required in the calculation of RVR is further governed by the decision, control, and display requirements. Thus, the question of the choice of a suitable wordlength for the signal data converter is integrally related to the rest of the RVR system as well. However, it is possible to make several observations on the wordlength required, without having to consider the accuracy of the rest of the RVR system. Thus, 12-bit wordlength for RVR calculations may be ruled out due to high errors and inadequate range ($-2048 \leq$ number ≤ 2047) available for calculations. On the other hand, 16-bit wordlength seems to be cost-effective in providing adequate accuracy for RVR calculations and adequate range ($-32768 \leq$ number ≤ -32767) for the representation of a number. A recent survey of minicomputers(1) indicates that more than 80% of the minicomputers available in the market have a 16-bit wordlength.

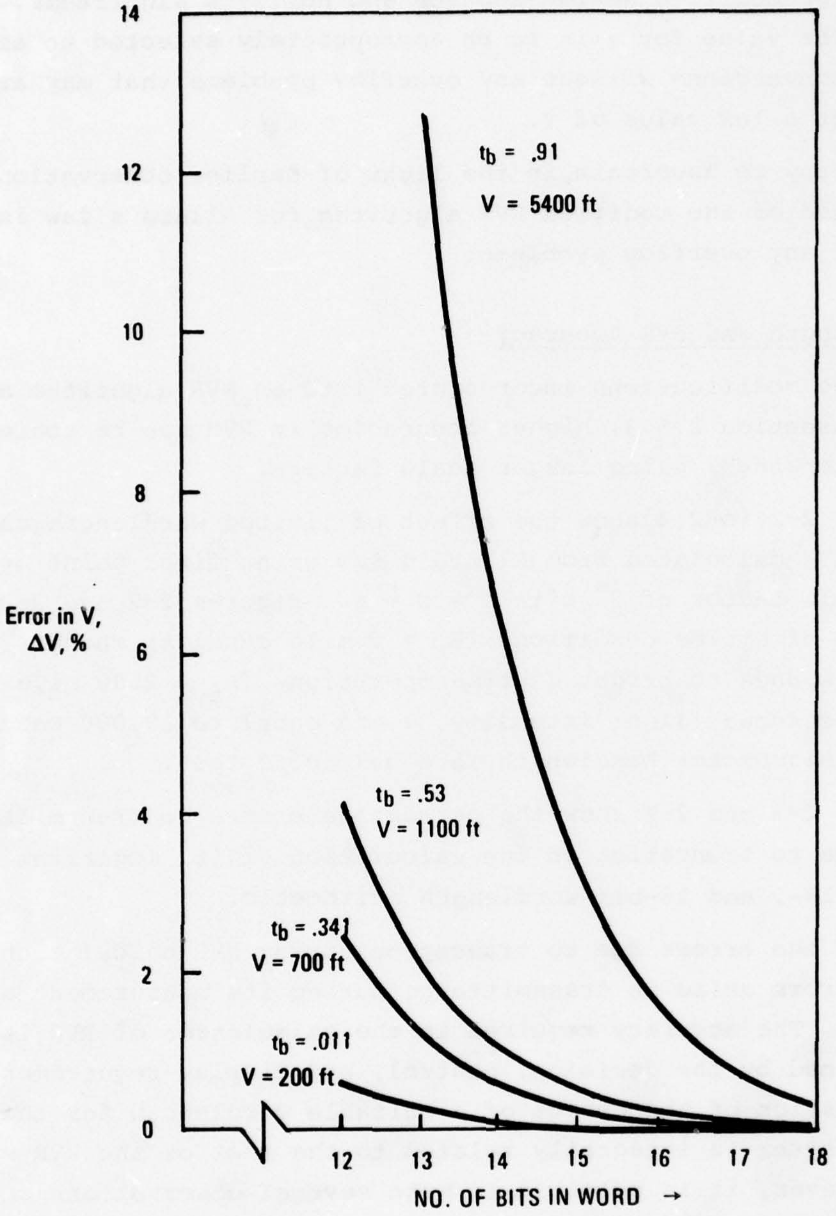

Figure 2-2. Truncation error in RVR due to limited wordlength in fixed-point arithmetic calculations of RVR using Allard's law for four different values of atmospheric transmittances t_b (and associated correct RVR) with E_t = 2 mile-candles, I = 10,000 candles, and baselength b = 60 feet.

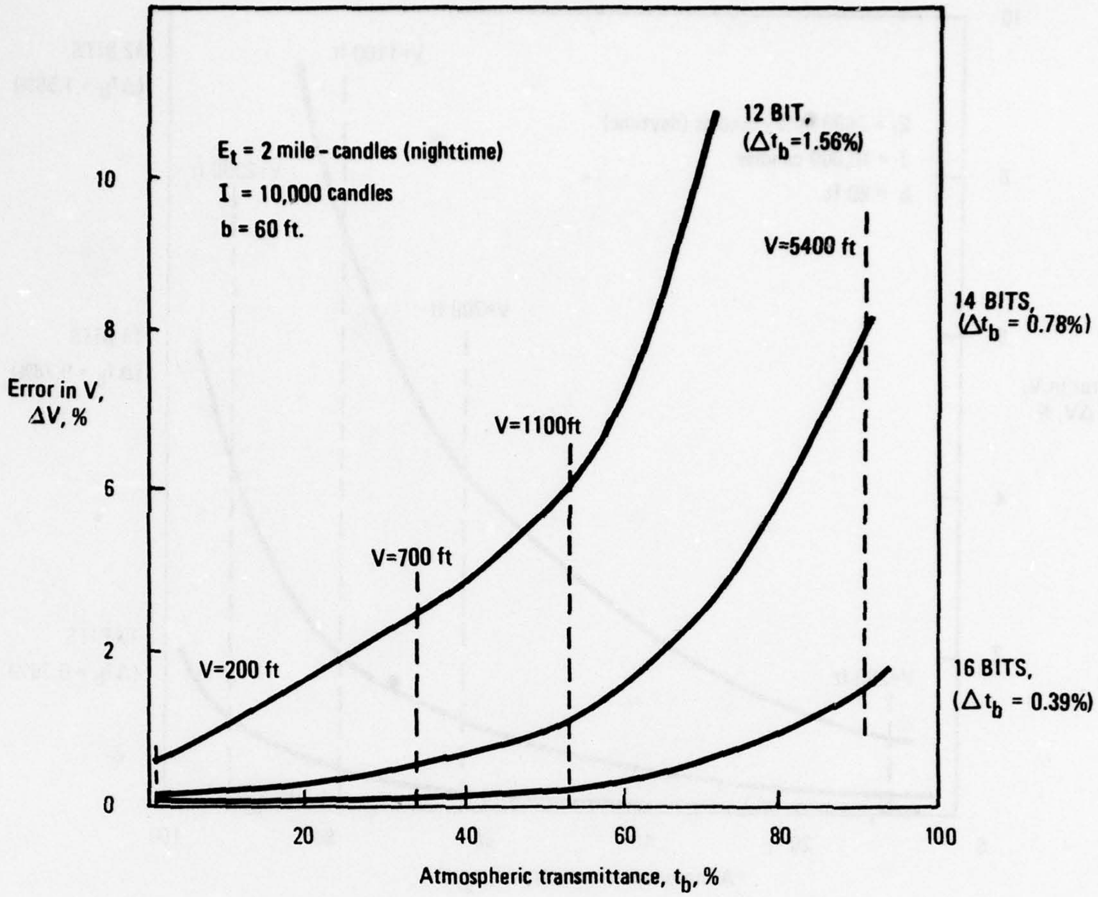

Figure 2-3. Plot of ΔV(%) vs t_b (%) for nighttime conditions showing the dependence of truncation error in the calculation of V on the atmospheric transmittance t_b for four different word-bit lengths.

2.6 SUMMARY AND CONCLUSIONS

Different aspects related to the determination of RVR have been discussed in this section. Efficient algorithms are developed for the computation of RVR from Allard's and Koschmieder's laws using fixed-point limited-wordlength calculations. It was shown that the order of accuracy attainable for a given wordlength is limited by two factors: errors due to truncation in the computation of the logarithm of atmospheric transmittance, and the overflow problems associated with limited wordlengths and large numbers. It was shown that the accuracy in the determination of the logarithm of a number using fixed-point arithmetic is of the order of 2^{N-5}, where N = number of bits in the signed binary

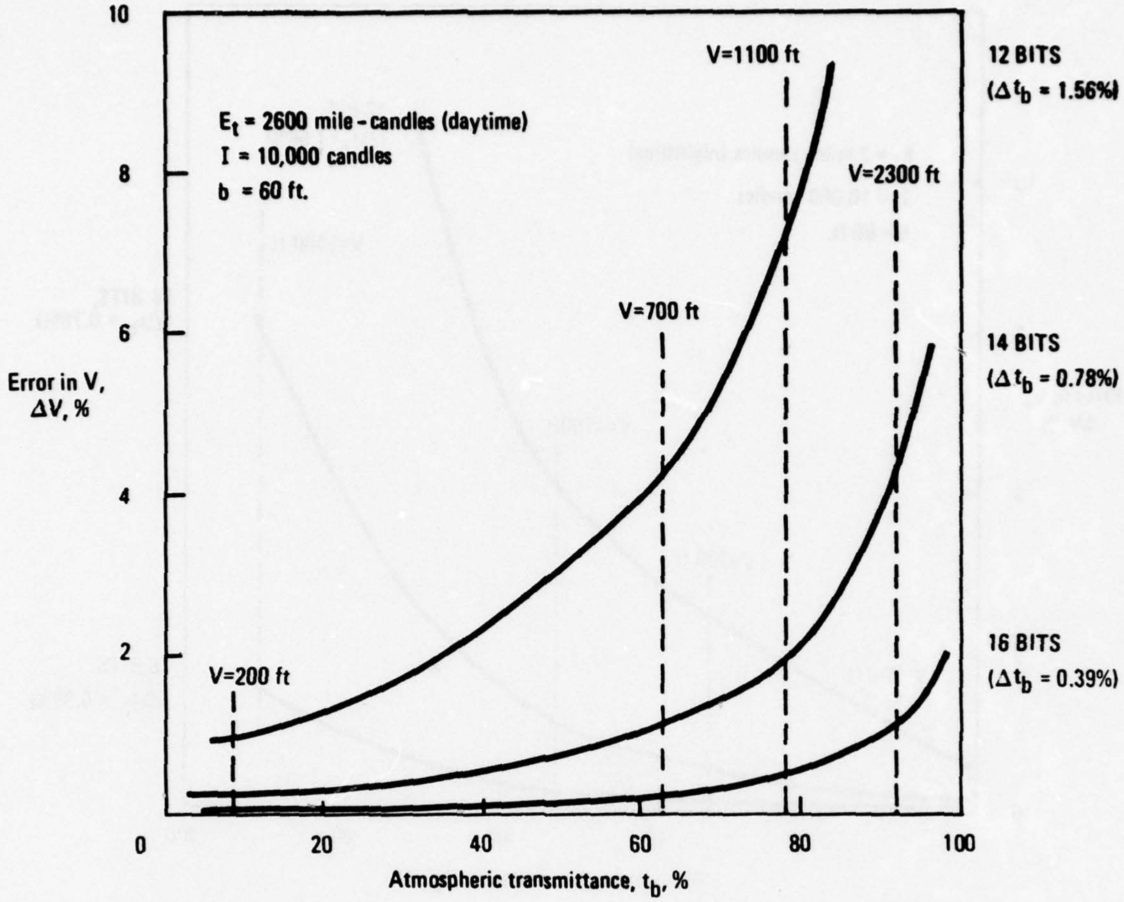

Figure 2-4. Plot of ΔV(%) vs t_b(%) for daytime conditions showing the dependence of truncation error in the calculation of V on the atmospheric transmittance t_b for four different word-bit lengths.

representation of a number. Relations were derived to project the order of accuracy available for a given visual environment and transmissometer baselength. It was seen that 12-bit wordlength does not meet the range requirements for the representation of a number and, moreover, the accuracy attainable with such a wordlength may be unacceptable. A 16-bit wordlength provides adequate range for the representation of a number and the accuracy available in the determination of RVR seems acceptable. Suitable measures necessary to achieve the projected order of accuracy, global convergence, and prevention of overflow during calculations were discussed for incorporation in the RVR algorithms.

3. VISIBILITY SYSTEM SOFTWARE

3.1 INTRODUCTION

This section describes the basic software modules required to implement a new airport visibility measuring and data-acquisition system described in more detail in Reference (1).

The design of the system software accounts for a variety of system configurations that may exist at different airport installations now and in the future. It is envisaged that the software package for a particular installation could be assembled by putting together the relevant software modules for each component and phase of operation of the system.

3.2 BASIC SOFTWARE PACKAGE

The basic software package is shown in Figure 3-1. It consists of three primary modules—VISIB, LKSERV, and EXECUT and two supporting modules ARITH and IOPKG. VISIB is a basic module that handles input, output, control, and calculations for the visibility system installation with the support of LKSERV, EXECUT, ARITH, and IOPKG.

LKSERV is primarily a time-keeping routine, servicing the interrupt requests generated by the real-time clock. It automatically updates the time of day and date after they are initially entered into the software from the executive program EXECUT. It is also used to clock I/O operations such as the transmissometer pulse count. LKSERV also provides a software interrupt to flag a status change in the runway-selector switch located on the display console.

EXECUT allows real-time software flow control through teletype command and response repertoire. Included is a test mode to check the modules VISIB, ARITH, and IOPKG. Visibility parameters are entered through the keyboard for test purposes. A diagnostic printout on the teletype is included. EXECUT also provides the necessary flexibility to update basic visibility parameters through a teletype input mode. Commands to interrogate the current time and date are included.

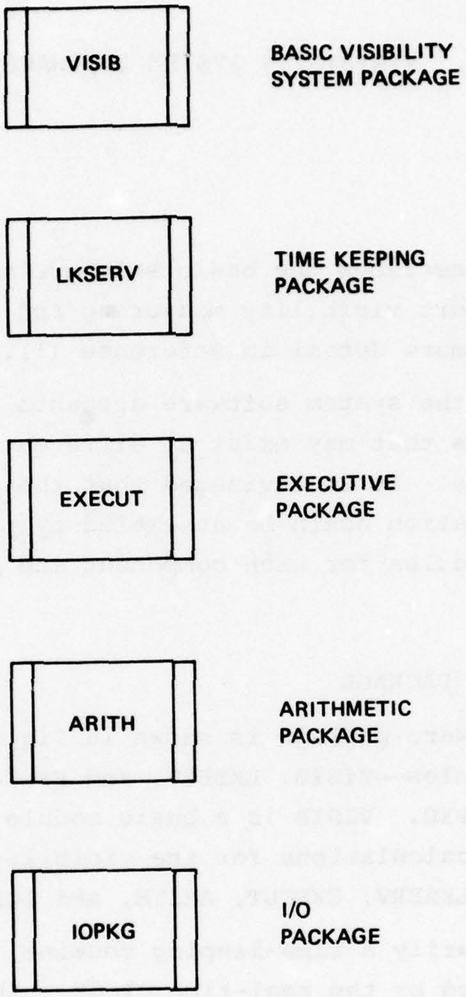

Figure 3-1. Primary modules comprising an airport visibility system software developed by the Draper Laboratory.

ARITH is a software math package to implement those functions not handled by hardware. Included are fixed-point multiply, divide, logarithm, and normalize. The ARITH module described in Appendix C was specifically developed for the experimental simulator-interface described in Section 5.

IOPKG is a software module to handle interface I/O communication. Appendix D contains a description of TTYPKG developed to permit I/O in various formats for a teletype interface.

These software modules are described in detail in the following subsections.

3.3 VISIB

VISIB constitutes the backbone of the airport visibility system software. As shown in Figure 3-2, it consists of four modules serving the following functions:

(1) Data input from visibility system sensors.

(2) Calculations to evaluate runway visual range (RVR), slant visual range (SVR), taxiway visual range (TVR), and ceiling in advanced modules.

(3) Output to displays, data logging, and system controls.

These four modules service more than one external device or sensor. For example, INPUT handles input data from the transmissometers, the TVR, SVR, and ceilometer sensors, and runway light intensity setting, etc. The modules consist of submodules, each handling a specific device or sensor. Dummy submodules replace the original when the device or sensor is nonexistent. New or replacement sensors are easily provided for through submodular software addition or replacement.

Subsections 3.3.1 to 3.3.4 further describe the four modules constituting VISIB. The software submodules associated with the evaluation of SVR, TVR, and ceiling, are sketched only briefly, since these systems and associated calculations are currently in various stages of investigation and development and consequently not well defined. In all probability, the data reduction for SVR and possibly ceiling will be performed by dedicated instrumentation and the result simply handed on to the above-referenced software for subsequent display. By contrast, the operations required to reduce tranmissometer data to visibility information is well documented and based upon the software described in Appendix C for the experimental simulator-interface.

3.3.1 INPUT

INPUT (see Figure 3-3) reads data from external sensors and devices and is stored until new data is read during the next input cycle. The operations of the submodules are explained in the following: TRIN (see

Figure 3-4) handles transmissometer pulse-rate data input. The atmospheric transmittance is averaged over a period of TW seconds. This is done by a pulse count over this period, handled by interface hardware. Alternative transmission modes of transmittance data would require a software modification.

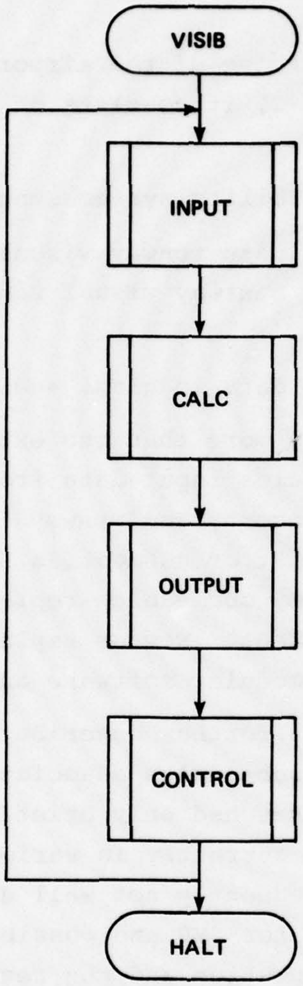

Figure 3-2. Basic airport visibility system package which handles during an update cycle: data inputs, calculations, transmission, recording display, and control functions associated with the system.

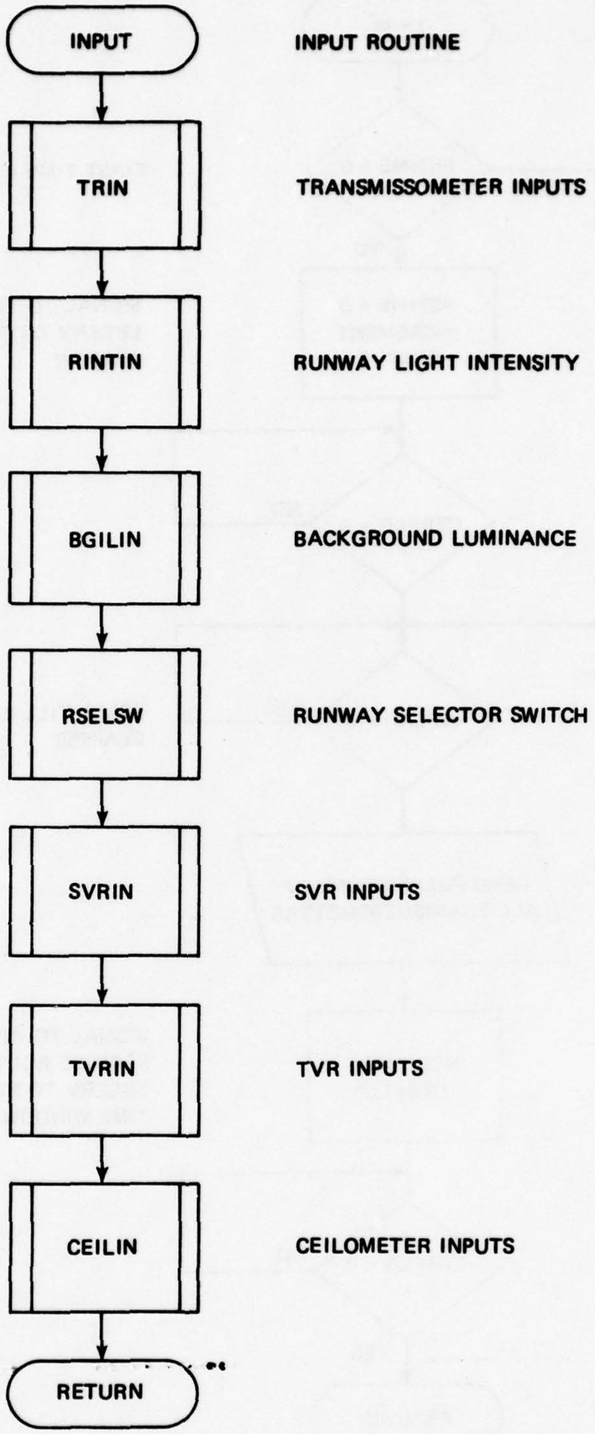

Figure 3-3. Routine to input data.

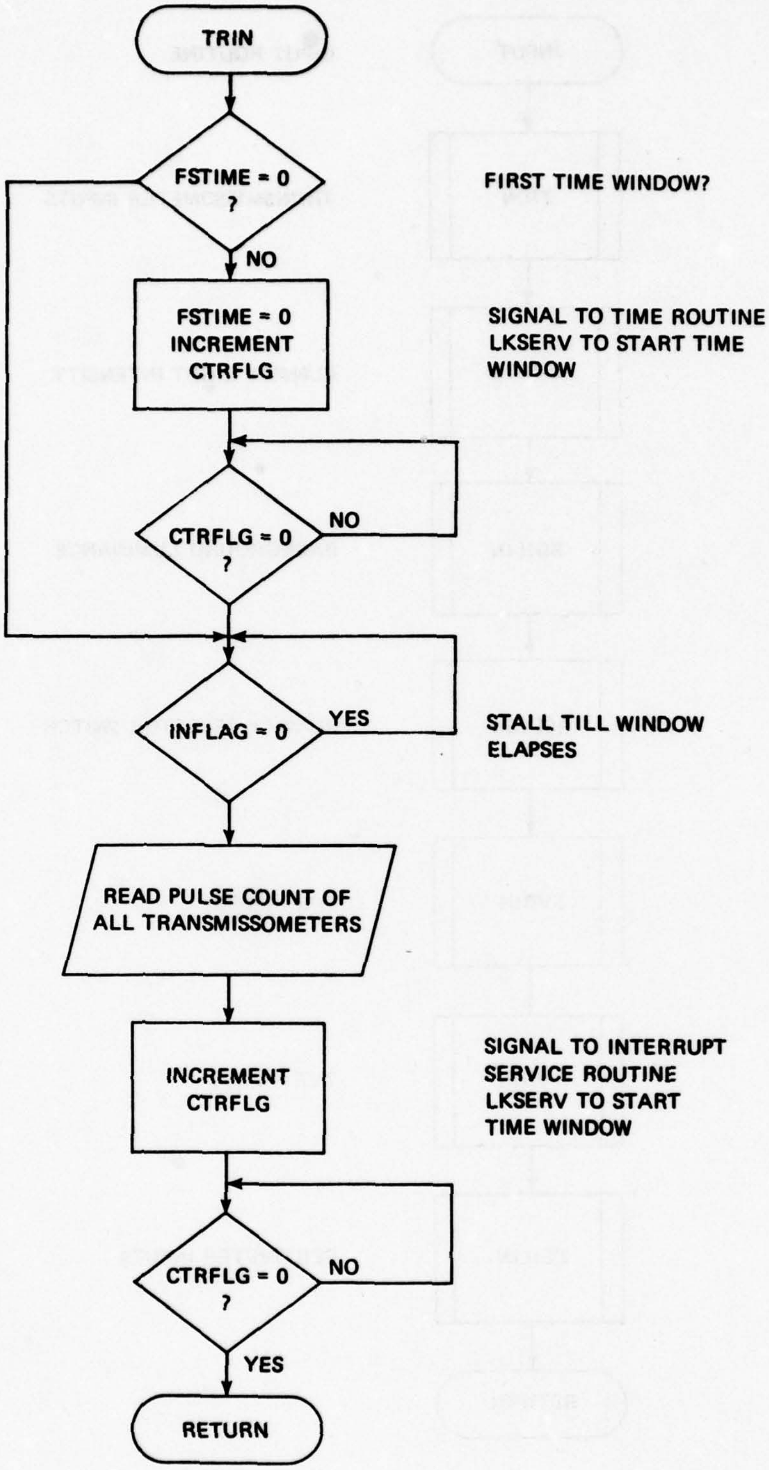

Figure 3-4. Transmissometer data input routine.

TRIN also decides when to start the time window for the pulse count. The actual enabling and inhibiting of the pulse count is handled by the time-keeping routine LKSERV, which services the real-time clock interrupt. Communication between TRIN and LKSERV is achieved through the flags CTRFLG and INFLAG. Setting CTRFLG flags LKSERV to enable the pulse count. LKSERV inhibits the count after TW seconds, and sets the flag INFLAG. When the pulse count begins, the VISIB program flow resumes through the basic cycle, INPUT, CALC, OUTPUT, and CONTROL, before returning to INPUT and TRIN for the start on the next time window. If the previous time window has elapsed (determined by the status of INFLAG), the pulse count of all transmissometers is read and the flag CTRFLG set to flag LKSERV to enable the pulse count once again. If the time window has not elapsed, the program waits. A provision has been made to prolong this waiting period every time VISIB is entered (such as at start-up or from EXECUT) when no previous pulse count is available. The timing relationship of these operations is shown in Figure 3-5.

RINTIN (see Figure 3-6) establishes the runway-light intensity for each runway, reading data from the intensity setting switch or from a light-intensity monitor. The nominal light intensities associated with each setting are available in the software.

BGILIN (see Figure 3-7) establishes the visual illuminance threshold (in mile-candles) either as a discrete level or a continuous measurement.

RSELSW (see Figure 3-8) reads the runway-selector switch on the display console. SVRIN, TVRIN, and CEILIN (see Figures 3-9 through 3-11) read data from the slant visual range, taxiway visual range, and ceilometer instrumentation.

3.3.2 CALC

CALC (see Figure 3-12) processes the visibility system sensor data to provide a measure of RVR, SVR, TVR, and ceiling, characterizing the visual environment.

RVRCAL (see Figure 3-13) evaluates the RVR corresponding to each measurement of transmittance, background luminance, and runway-light intensity. The RVR values are stored until recalculated in the next cycle. RVRCAL is serviced by ITER (see Figure 3-14) which evaluates RVR using either Allard's Law or Koschmieder's Law.

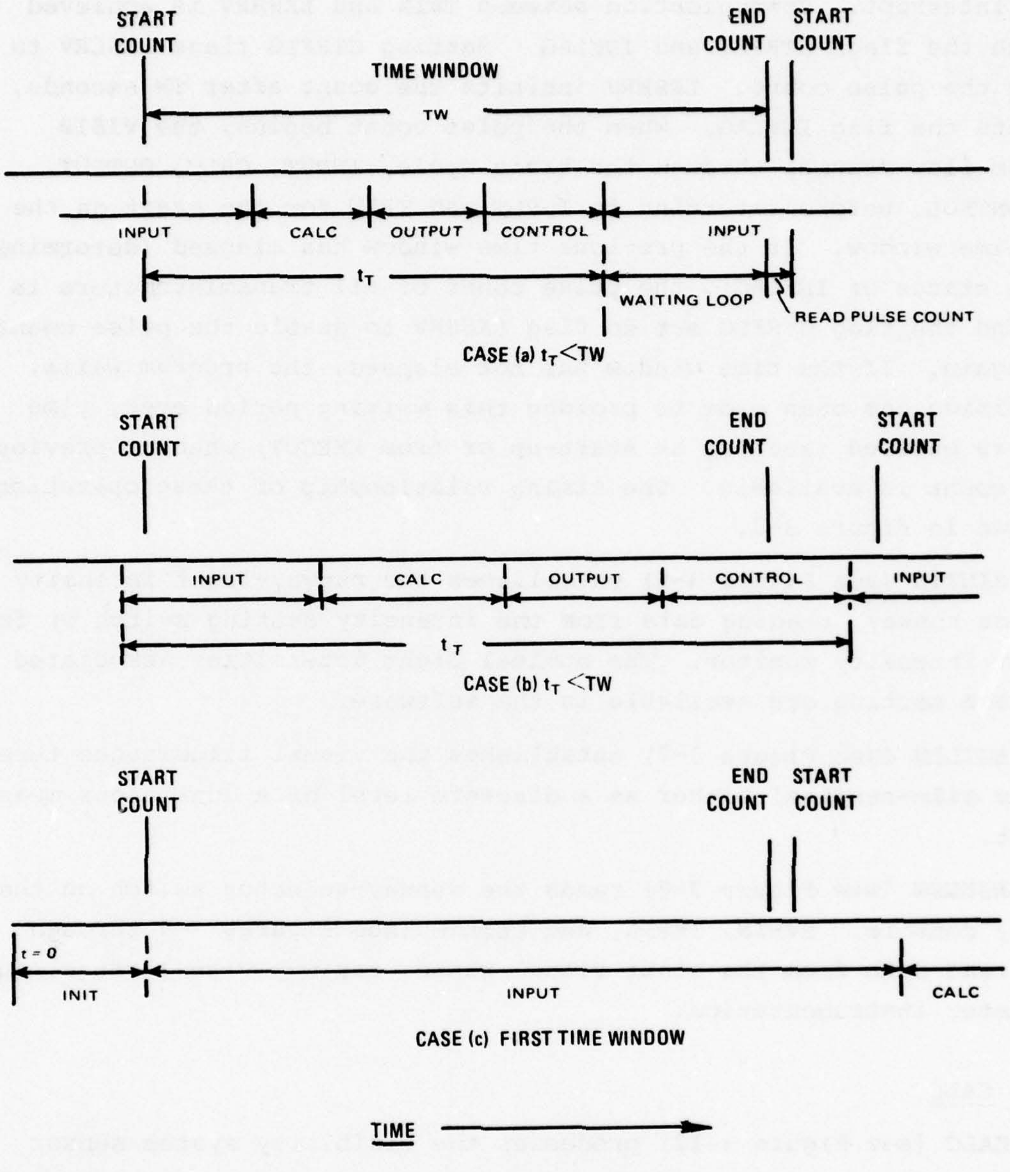

Figure 3-5. Timing relationships for different software modules with respect to the transmissometer pulse counting during an update cycle.

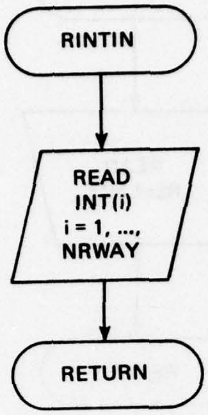

Figure 3-6. Runway-light-intensity input routine.

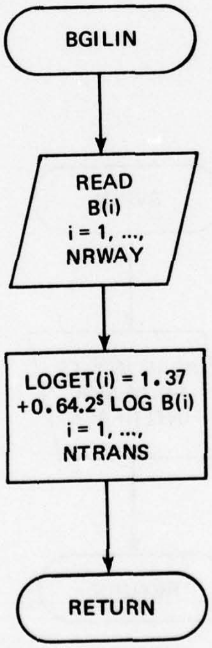

Figure 3-7. Sky-background-luminance input routine.

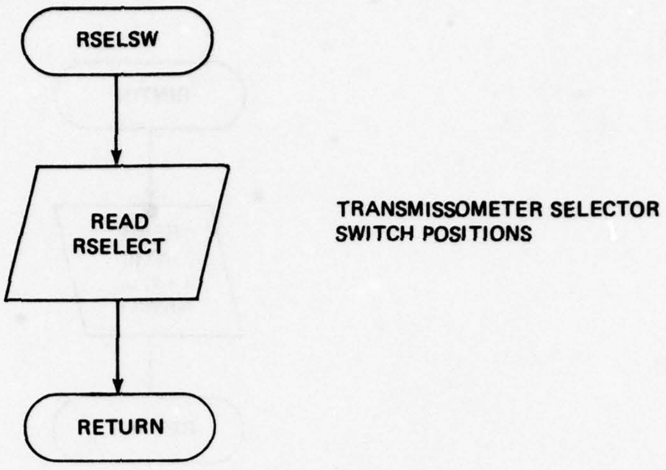

Figure 3-8. Routine to read transmissometer selector switch position for RVR display.

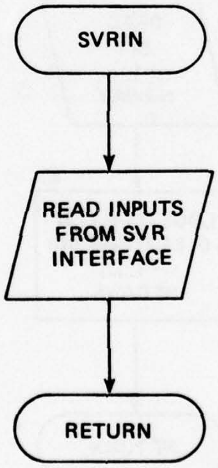

Figure 3-9. Routine to read inputs from SVR interface.

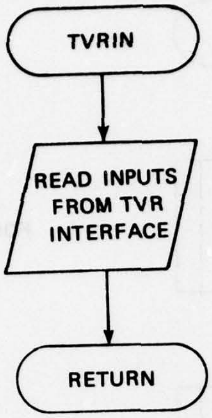

Figure 3-10. Routine to read TVR inputs.

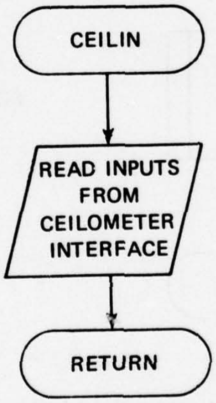

Figure 3-11. Routine to read ceilometer inputs.

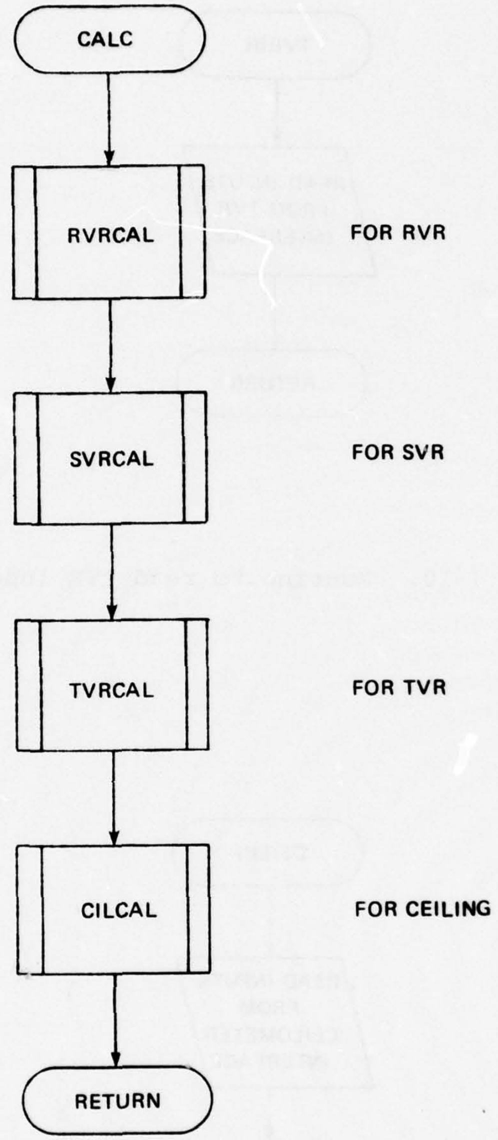

Figure 3-12. Airport visibility system parameters calculation routine.

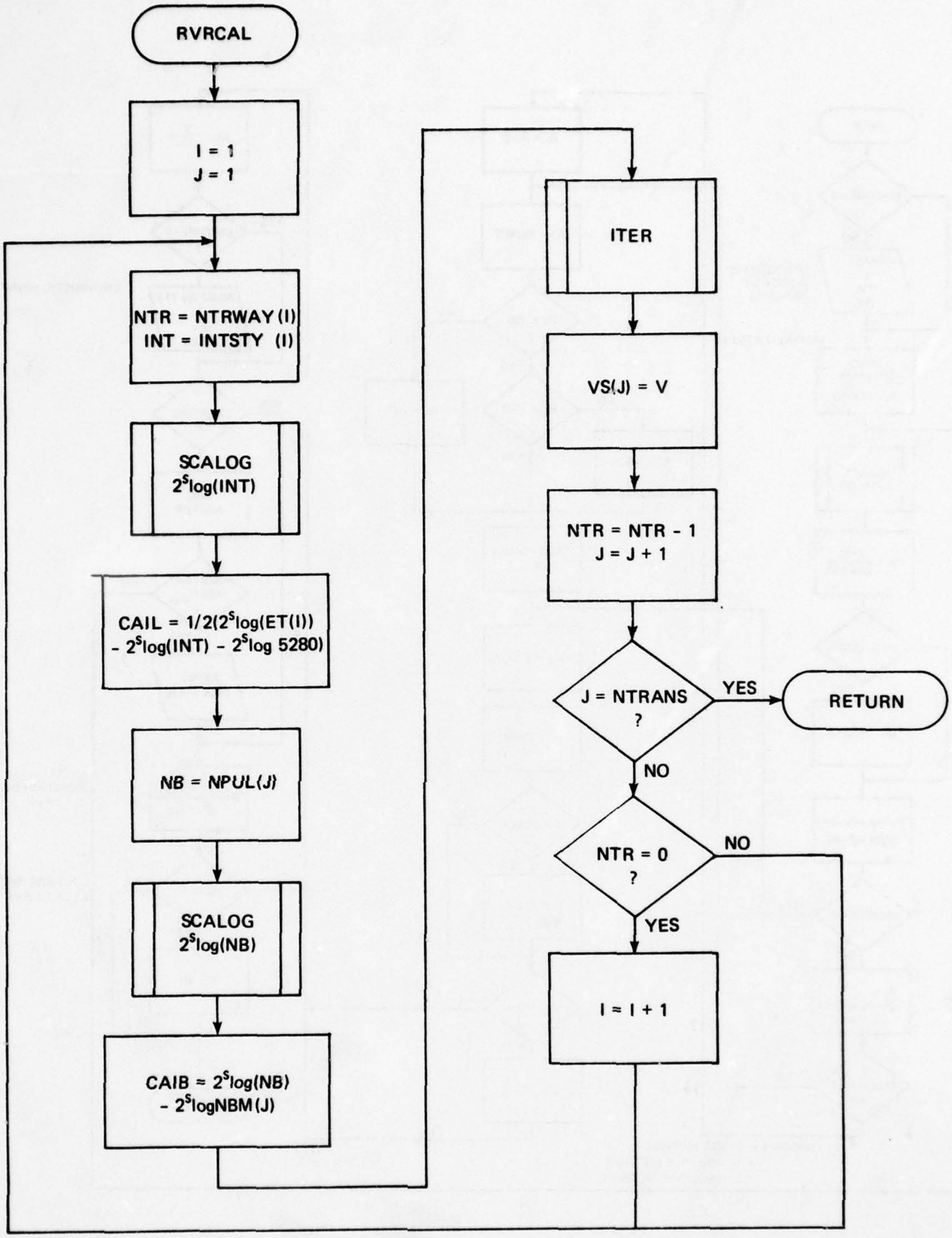

Figure 3-13. Routine to compute RVR.

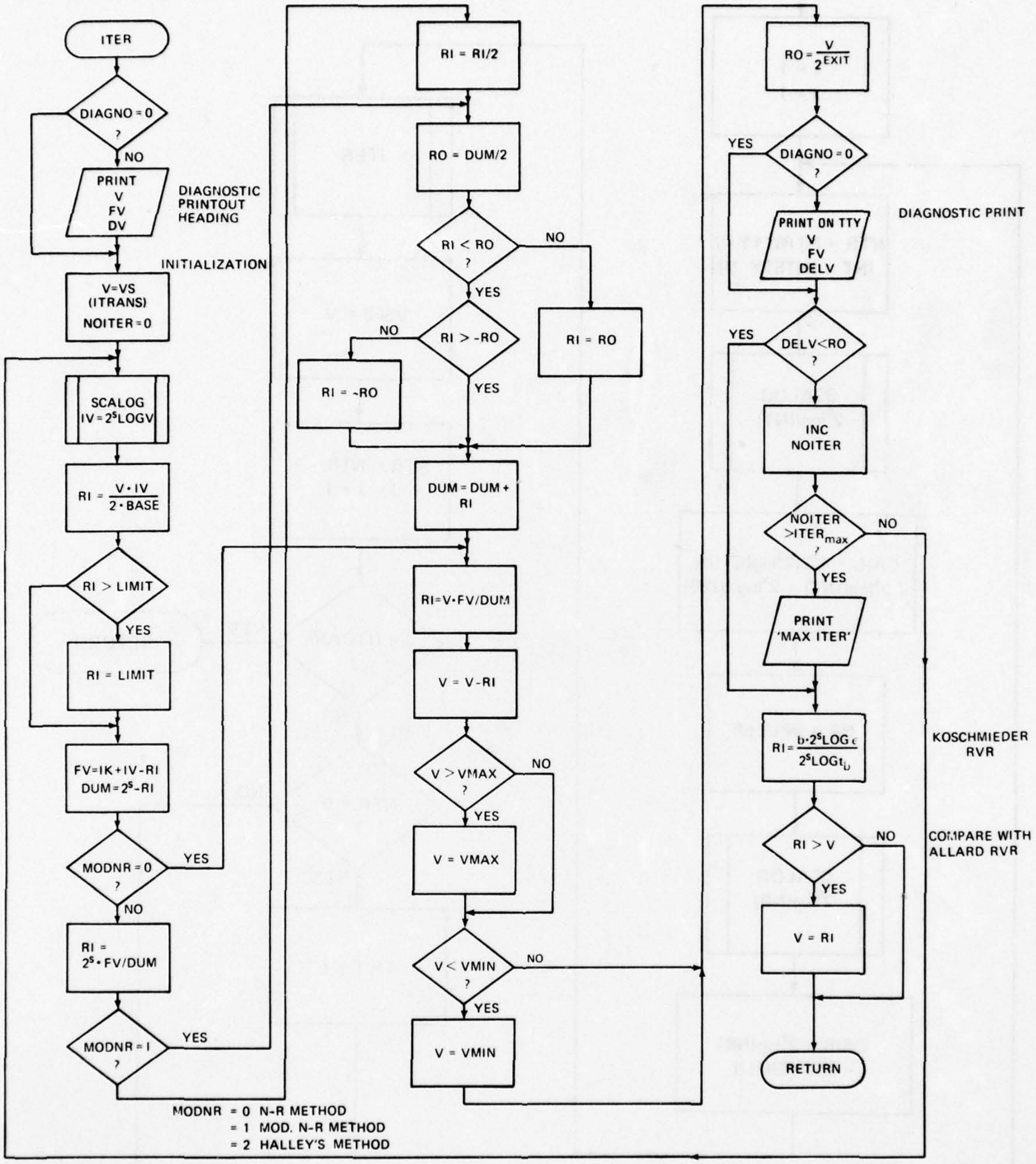

Figure 3-14. Iteration routine to compute RVR.

ITER evaluates RVR in fixed-point arithmetic with a scale factor of 2**SCALE.[*] An algorithm based on Allard's Law requires an iterative solution; the maximum number of iterations is ITERMAX. If the solution has not converged before the limiting number of iterations ($\Delta V_i > V_i$/2**EXIT), an error message is generated. Three iterative methods are coded, namely Newton-Raphson (N-R), modified N-R, and Halley's method. The software switch MODNR selects the desired algorithm. The iterative algorithms are described in Subsection 2.3. The algorithms have been carefully structured to ensure global convergence and maximum accuracy for the wordlength.

SVRCAL, TVRCAL, and CILCAL (see Figures 3-15 through 3-17) are the submodules supplying SVR, TVR, and ceiling.

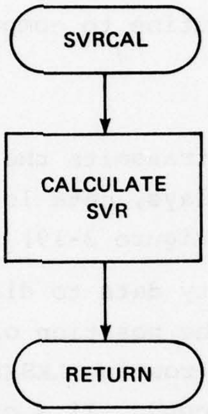

Figure 3-15. Routine to compute SVR.

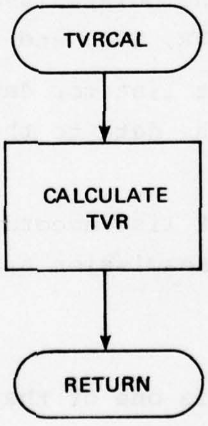

Figure 3-16. Routine to compute TVR.

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[*] Symbol ** stands for exponentiation.

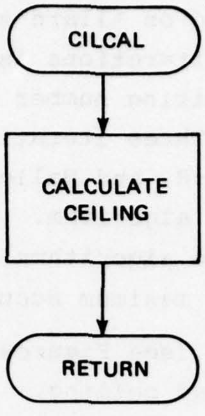

Figure 3-17. Routine to compute ceiling.

3.3.3 OUTPUT

OUTPUT (see Figure 3-18) transmits the processed visibility information to local and remote displays, data logging system, and data uplink transmitter. OUTPUT (see Figure 3-19) submodules are as follows.

OUTATC transmits visibility data to display consoles. The specific data transmitted depends upon the position of the runway-selector switch. The software interrupt routine LKSERV interrogates the position of the runway selector every second. If a change has occurred, the new visibility data is immediately transmitted to the displays by STROBE (see Figure 3-20).

ATCRVR, ATCSVR, ATCRVR, and OUTREC (see Figures 3-21 through 3-29) are the submodules displaying SVR, TVR, and ceiling information.

OUTREC assembles an output list for data logging according to a specified format, and outputs the data to the teletype or other data-logging medium.

OUTITS assembles an output list according to a specified format for output to an information-transmission system.

3.4 LKSERV

LKSERV (see Figure 3-30) is one of the three main packages referred to in Figure 3-2. It is basically a time-keeping routine

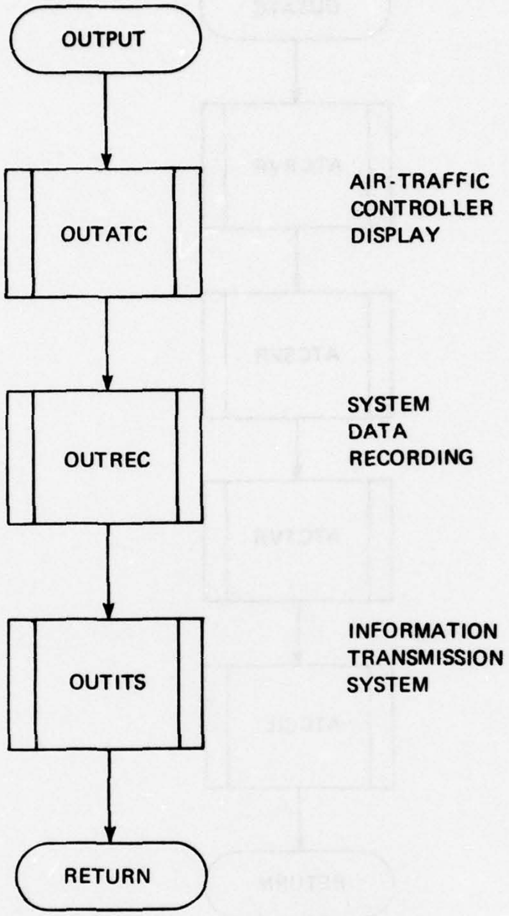

Figure 3-18. Output routine.

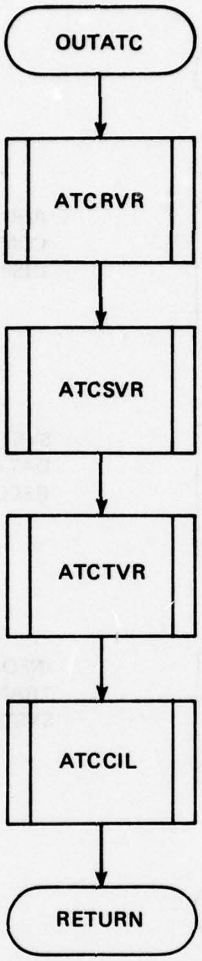

Figure 3-19. Routine to service air-traffic-controller display.

which operates at a higher priority level than the other software routines. LKSERV uses the hardware line-frequency real-time clock. When the latter generates an interrupt, control is transferred to LKSERV; upon return from LKSERV, the main program resumes from the point of interruption.

LKSERV is also used to enable and inhibit the transmissometer pulse count. The routine inhibits the count when the time window has reached the specified width, TW seconds. Initiation of the time-window occurs in TRIN (a submodule of VISIB) and is communicated to LKSERV by a flag.

LKSERV also includes a software interrupt to service a display update request signalled by the runway-selector switch. LKSERV interrogates the switch status every second. If a change has occurred in the last record, control is briefly passed to STROBE (see Figure 3-20). The latter strobes (using OUTATC) the new information to the displays, then a return is made to LKSERV. STROBE operates at a lower priority level than LKSERV.

The time and date are automatically updated while the program runs uninterrupted. A restart requires an initialization of time and date. The accuracy of the time and date is that of the line-frequency real-time clock.*

3.5 EXECUT

EXECUT (see Figure 3-31) provides real-time monitor control of the software from the keyboard. The monitor is entered by hitting the control-C key on the keyboard. EXECUT acknowledges by typing the character '.' on the teletype.** A string of characters terminated by

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* The execution time of LKSERV must be less than the interrupt period, otherwise the time-keeping ability of LKSERV would be lost. This is not a severe limitation, since the functional requirements of LKSERV which determine the execution time are minimal.

** IOPKG services the interrupt generated by keyboard inputs and passes control to EXECUT when the control-C key is hit. The details may be found in TTYIO of the experimental simulation software described in Appendix D.

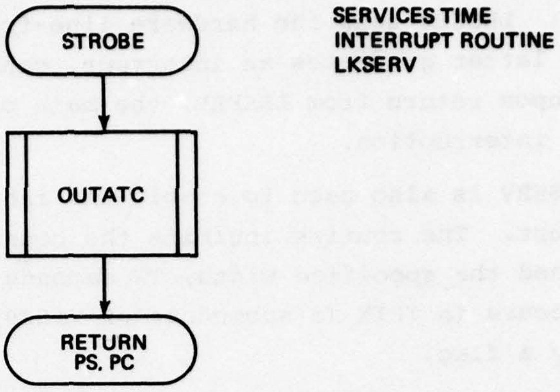

Figure 3-20. Routine to service air-traffic-control display.

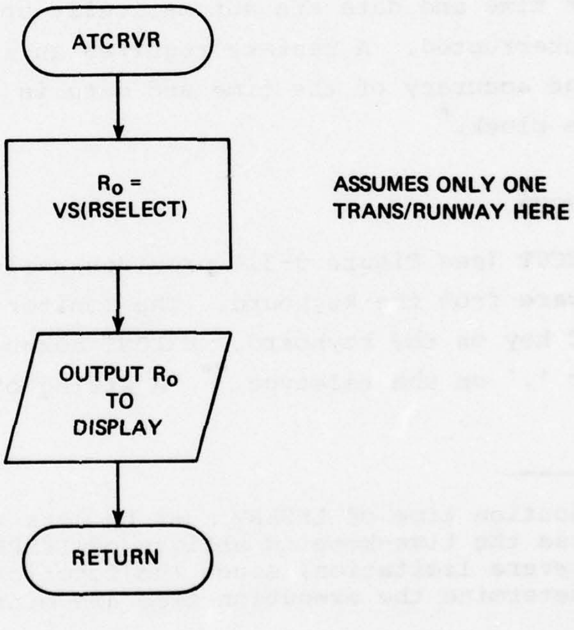

Figure 3-21. Routine to display RVR.

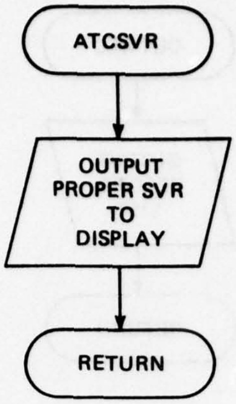

Figure 3-22. Routine to display SVR.

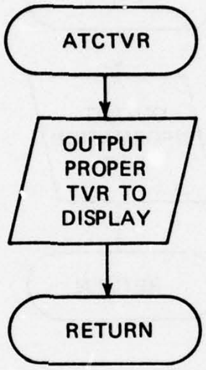

Figure 3-23. Routine to display TVR.

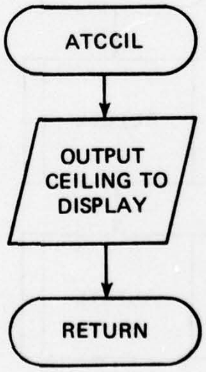

Figure 3-24. Routine to display ceiling.

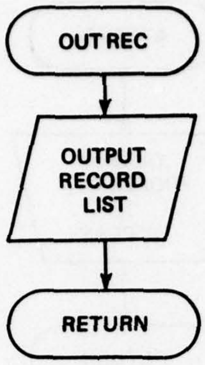

Figure 3-25. Routine for system data recording.

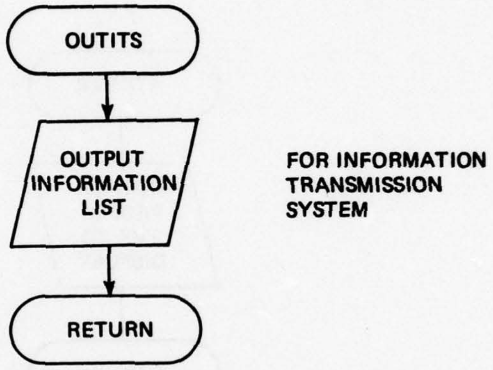

Figure 3-26. Routine for information transmission system.

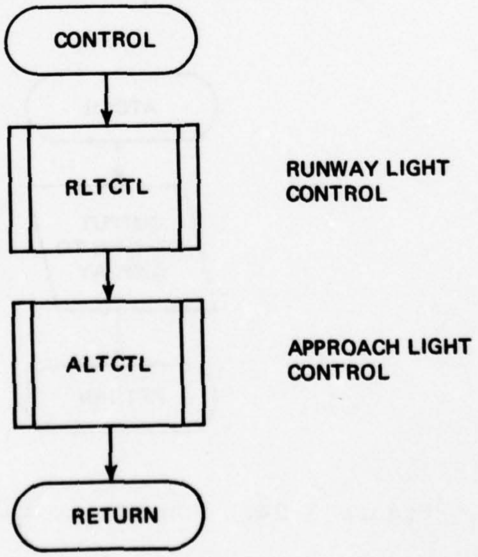

Figure 3-27. Light control routine.

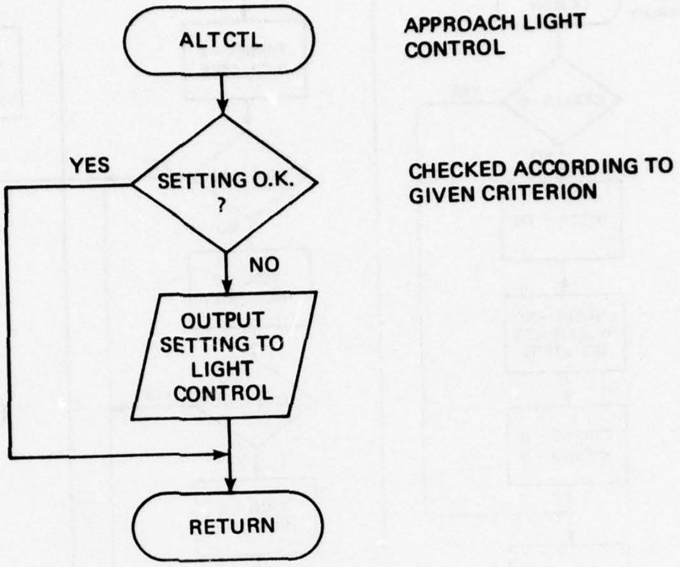

Figure 3-28. Approach light control routine.

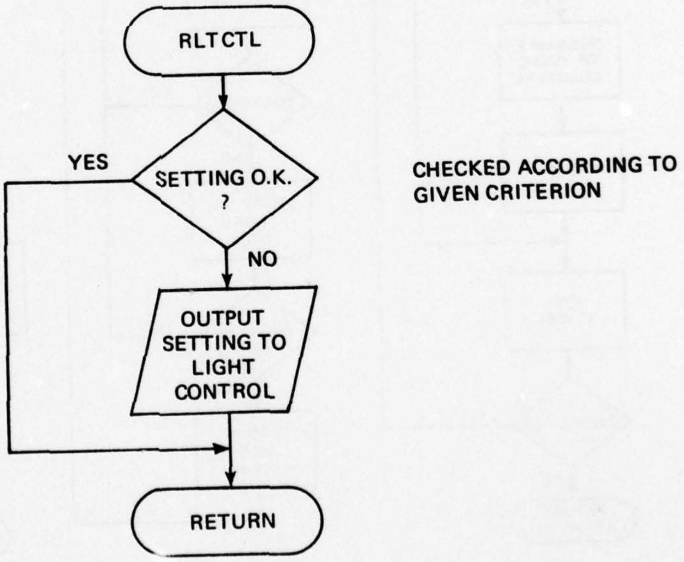

Figure 3-29. Runway light intensity control routine.

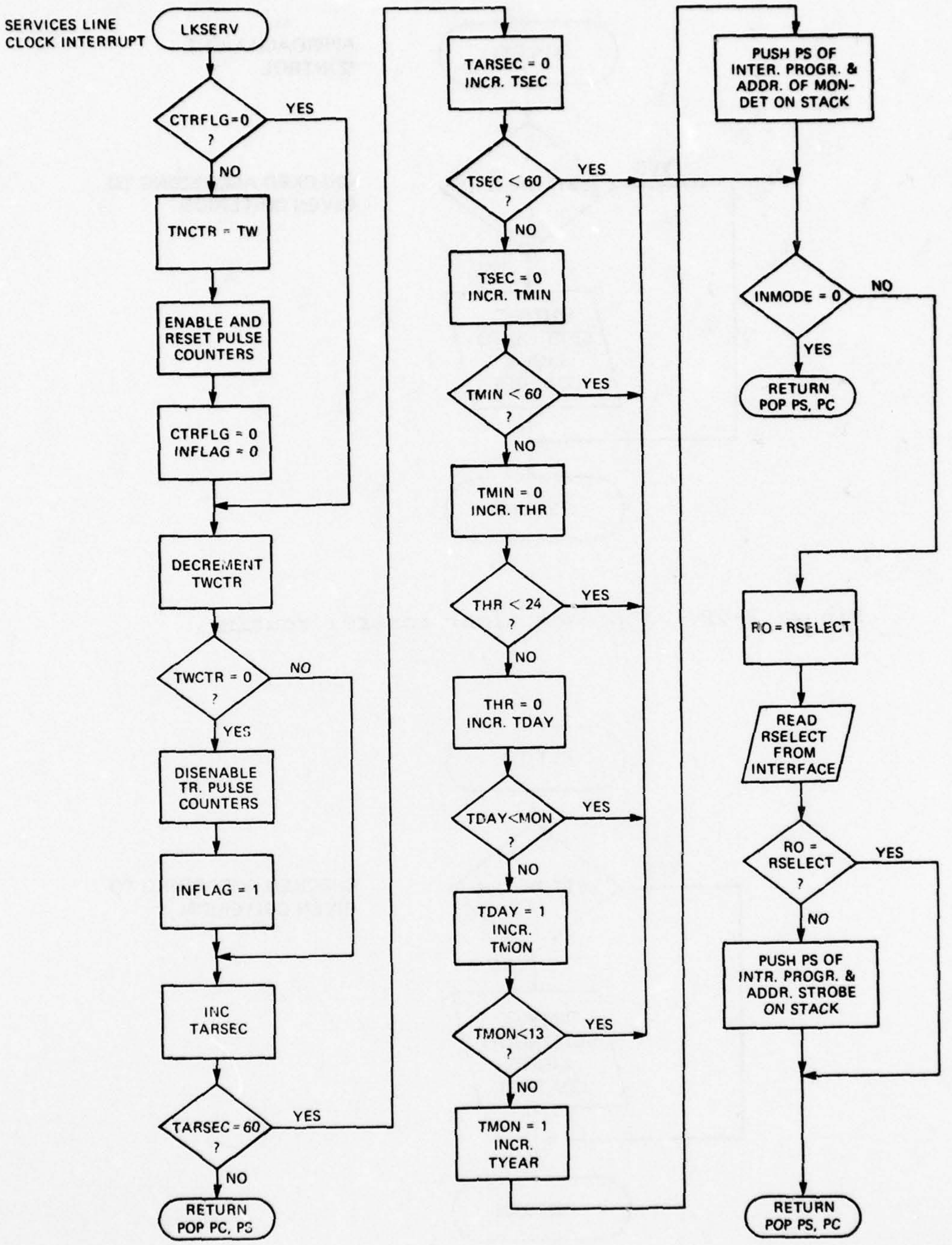

Figure 3-30. Routine to keep time and service time-related control functions.

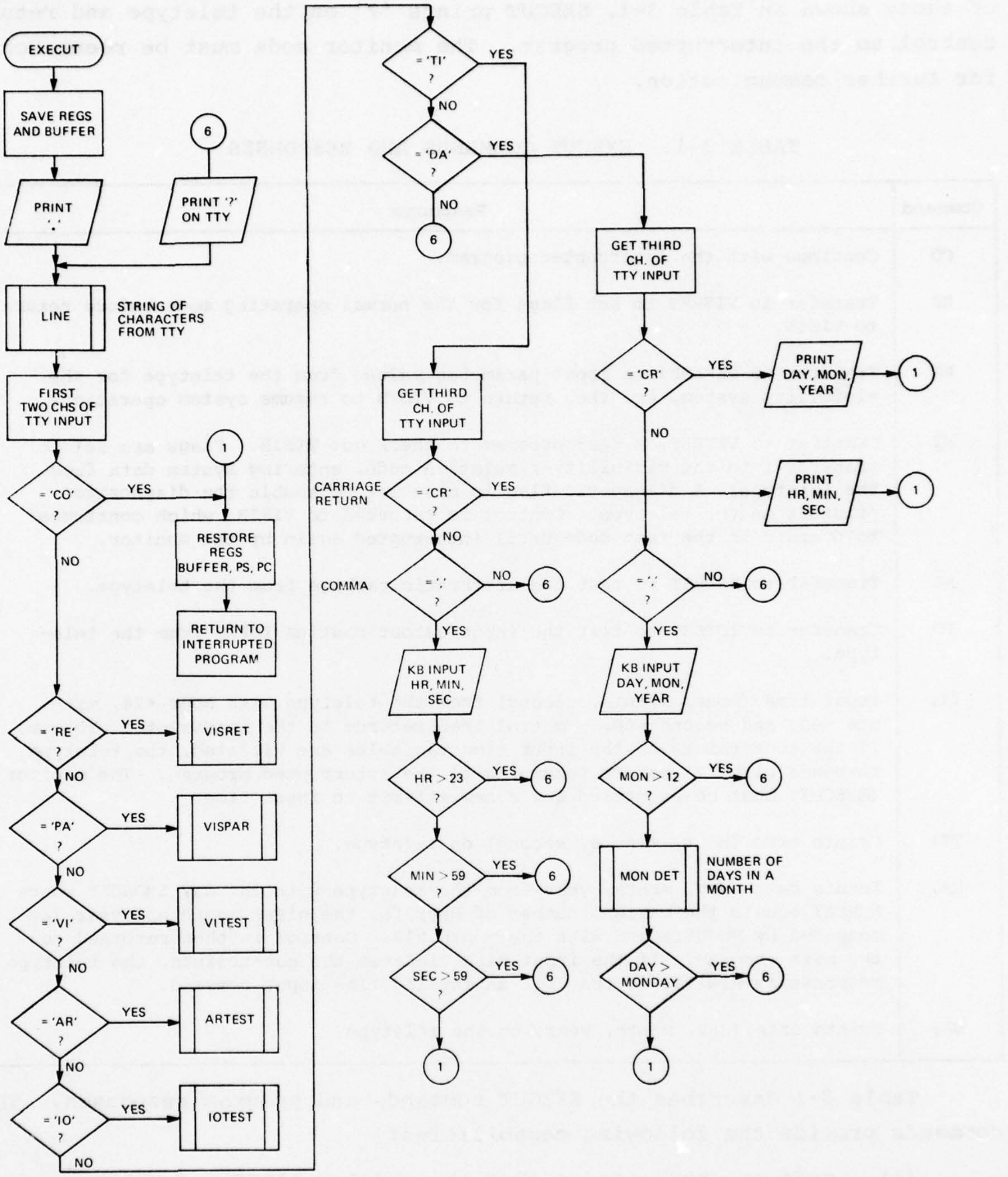

Figure 3-31. Executive routine.

a comma or carriage return (referred to in the flow diagrams as CR or ↓). can be input from the teletype. If the command is not recognized as one of those shown in Table 3-1, EXECUT prints '?' on the teletype and returns control to the interrupted program. The monitor mode must be reentered for further communication.

TABLE 3-1. EXECUT COMMANDS AND RESPONSES

Command	Response
CO	Continue with the interrupted program.
RE	Transfer to VISRET to set flags for the normal operating mode before return to VISIB.
PA	Transfer to PARASET to input parameter values from the teletype for the visibility system, and then return to VISIB to resume system operations.
VI	Transfer to VITEST, a test program to check out VISIB. Flags are set to transfer into the visibility-simulation mode, entering system data from the teletype. A diagnostic flag is also set to enable the diagnostic printout on the teletype. Control is returned to VISIB, which continues to operate in the test mode until interrupted again by the monitor.
AR	Transfer to ARTEST to test the arithmetic package from the teletype.
IO	Transfer to IOTEST to test the input/output routine IOPKG from the teletype.
TI,	Input time (hour, minute, second) from the teletype with hour <24, minute <60, and second <60. Control then returns to the interrupted program. If the constraints on the input time variables are violated, the teletype responds with '?' before returning to the interrupted program. The monitor (EXECUT) must be reentered for a new attempt to input time.
TI↓	Prints time (hour, minute, second) on teletype.
DA,	Inputs date (day, month, year from the teletype with the day ≤MONDAY where MONDAY equals the maximum number of days for the given month and year (as computed by MONDET) and with the month ≤12. Control is then returned to the main program. If the input data violates the constraints, the teletype response is similar to that for an invalid time input command.
DA↓	Prints date (day, month, year) on the teletype.

Table 3-1 describes the EXECUT commands and program responses. The commands provide the following capabilities:

(1) Software programs to test the modules IOPKG and VISIB.* Control is returned to the interrupted program be reentering the monitor mode and issuing the return command, RE.

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*See Appendix D for details of these test programs.

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THE DEVELOPMENT OF A SIGNAL DATA CONVERTER FOR AN AIRPORT VISIB--ETC(U)
AUG 75 H C INGRAO, M YAFFEE, M F CARTWRIGHT
UNCLASSIFIED TSC-FAA-74-20 FAA-RD-75-65 NL

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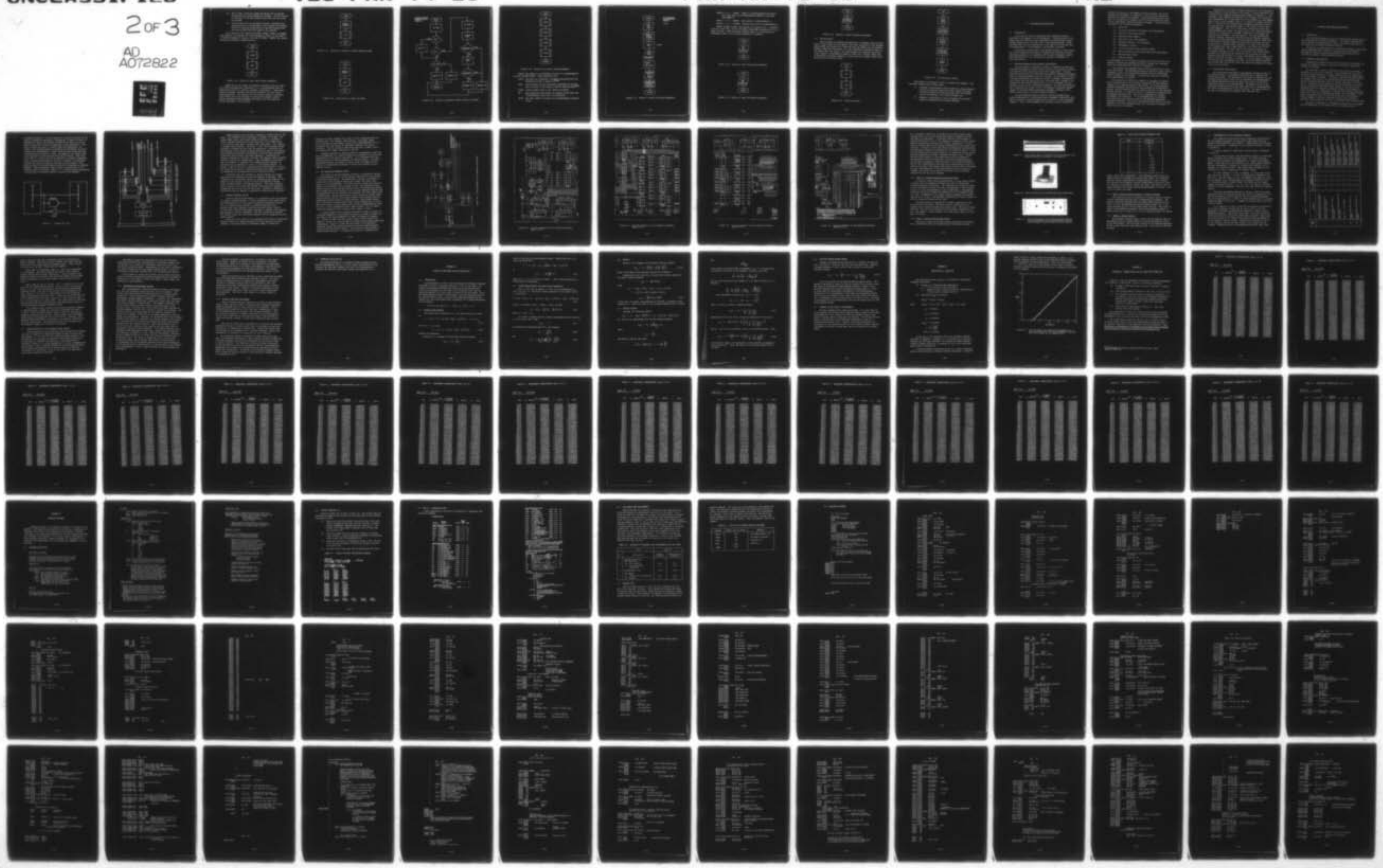

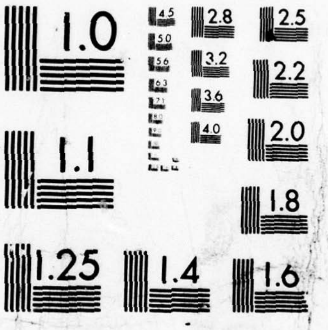

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-

(2) Basic airport visibility system parameters may be changed by entering new values through the teletype. Control returns to the start of the main program VISIB after the new values are entered.

(3) Time and date may be interrogated through a teletype entry. Initialization of time and date is also through the teletype. Control is returned automatically to the main program after the time and date have been typed on the teletype.

The functions of the submodules VISPAR, VISRET, VITEST, and MONDET (see Figures 3-32 through 3-35) are delineated in Table 3-1 and require no further elaboration except in the case of VISPAR. PARSET, the routine and services VISPAR, is described next.

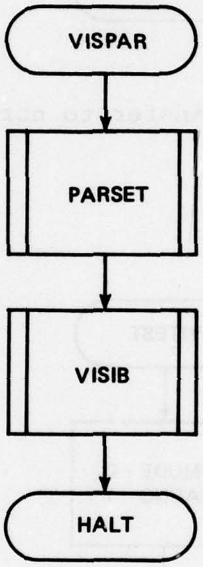

Figure 3-32. Routine to enter basic system parameters.

PARSET sets up the system and software parameters which are basic to a visibility-measuring installation, i.e., the parameters that are essentially fixed for a specific equipment configuration. These parameters are software variables that may be altered at any time during program operation. The parameters may be entered through a convenient input medium such as the teletype or through the computer console. Several submodules comprise PARSET (see Figure 3-36) and these are briefly described in the following.

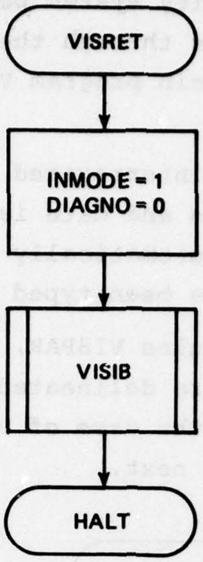

Figure 3-33. Routine for transfer to normal operating mode.

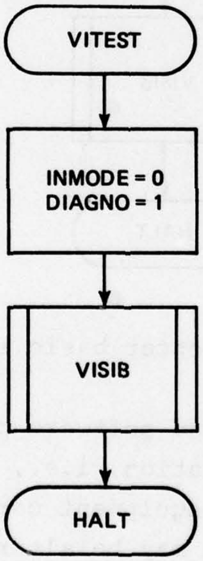

Figure 3-34. Test routine to check out VISIB.

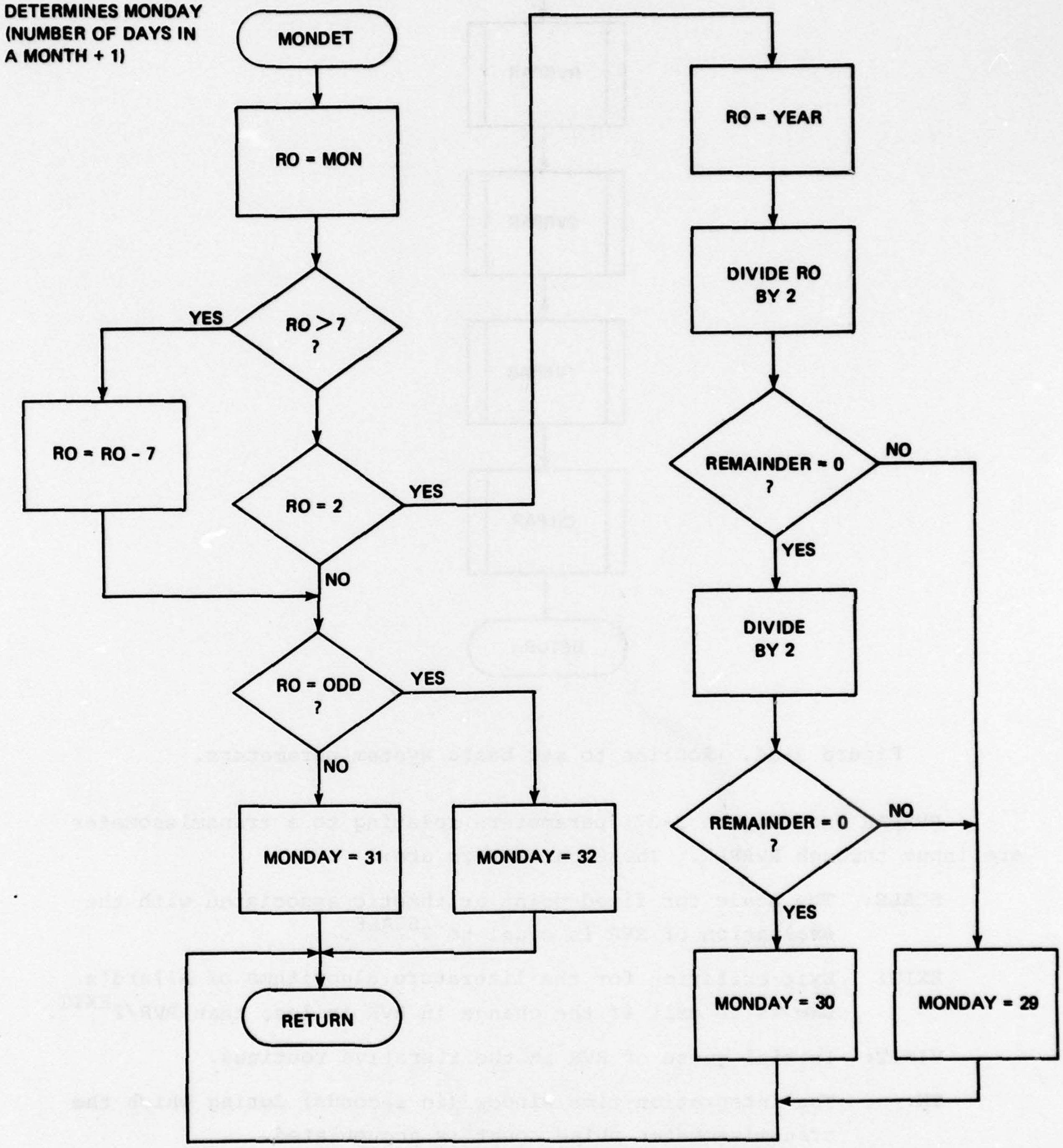

Figure 3-35. Routine to determine number of days in a month.

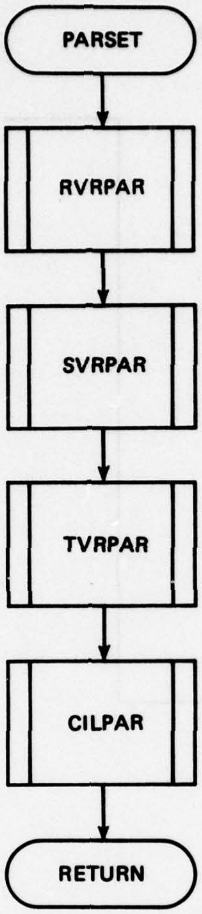

Figure 3-36. Routine to set basic system parameters.

RVRPAR (see Figure 3-37) parameters relating to a transmissometer are input through RVRPAR. These parameters are:

SCALE: The scale for fixed-point arithmetic associated with the evaluation of RVR is equal to 2^{SCALE}.

EXIT: Exit criterion for the literature algorithms of Allard's Law is to exit if the change in RVR is less than $RVR/2^{EXIT}$.

VINIT: Initial guess of RVR in the iterative routines.

TW: The integration time window (in seconds) during which the transmissometer pulse count is accumulated.

NRWAY: The total number of runways with transmissometer installations.

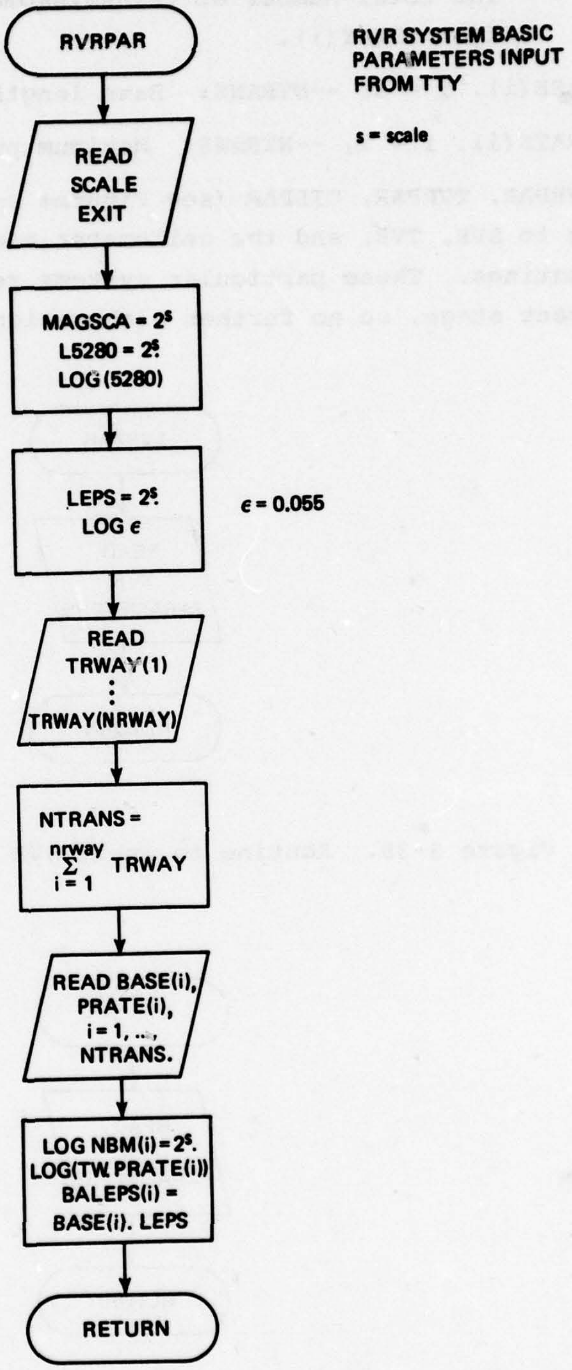

Figure 3-37. Routine to input RVR system parameters.

TRWAY(i), i = 1, --NRWAY: Number of transmissometers per runway. The total number of transmissometers NTRANS is evaluated from TRWAY(i).

BASE(i), i = 1, --NTRANS: Base length of transmissometer i.

PRATE(i), i = 1, --NTRANS: Maximum pulse rate of transmissometer i.

SVRPAR, TVRPAR, CILPAR (see Figures 3-38 through 3-40). Parameters relating to SVR, TVR, and the ceilometer measurement system are set up in these routines. These particular systems remain in the conceptual or development stage, so no further elaboration is possible.

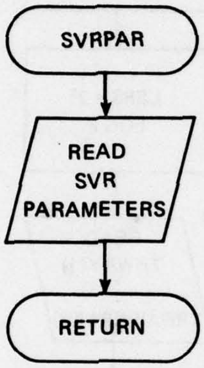

Figure 3-38. Routine to input SVR system parameters.

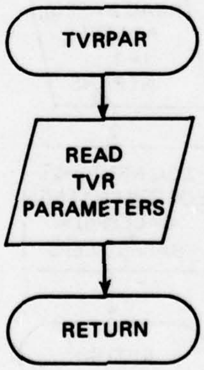

Figure 3-39. Routine to input TVR system parameters.

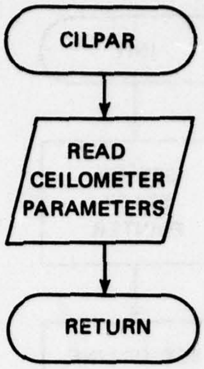

Figure 3-40. Routine to input ceilometer parameters.

3.6 INITIALIZATION

Some software and hardware initialization is necessary when the software is first loaded into the memory. The first instruction of the software module START (see Figure 3-41) forms the starting address for the software modules loaded into the memory. The first instruction transfers control to the module INIT (see Figure 3-42) which handles the requisite initializations. Control is subsequently passed to VISIB and it remains there until an alternative operative command is entered from the teletype (after first entering into the monitor mode).

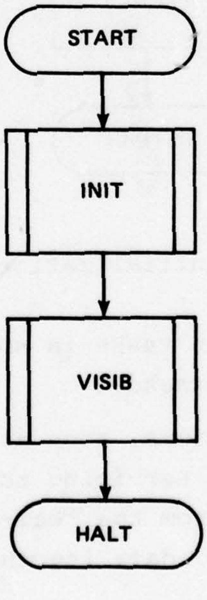

Figure 3-41. Starting routine.

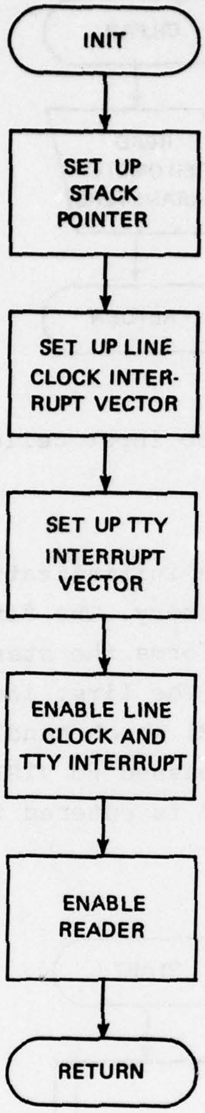

Figure 3-42. Initialization routine.

INIT handles initialization tasks in software and hardware. The following include some of those tasks:

(1) Software initializations, such as setting up stack pointers, setting up interrupt servicing routine vectors to handle interrupt requests from the real-time clock, I/O devices such as the teletype, data logging systems, etc.

(2) Hardware initializations, such as enabling the interrupt capability associated with external devices.

4. MINICOMPUTER CONFIGURATION

4.1 INTRODUCTION

At the core of the data acquisition and computation systems described in this appendix is the minicomputer. Characteristics of the latter used in a repetitive data acquisition and control mode include minimum configuration, low cost, and a fixed storage program. These characteristics are also descriptive of the upper end of the new class of microprocessor, or microcomputer, now generally available.

Two specific configurations are discussed briefly in this section. One is that configuration chosen to implement the simulator-interface described elsewhere in this appendix, and the other represents a desirable specification of the configuration required to implement the field installation.

4.2 SIMULATOR-INTERFACE MINICOMPUTER CONFIGURATION

The minicomputer configuration chosen to implement the simulator-interface was required to meet certain criteria not necessarily relevant to the eventual data acquisition and control application. The most important of these was the requirement for powerful software development tools to reduce programming cost to a minimum. It was desired to acquire a minimum-configuration minicomputer system to implement the demonstration control and data acquisition task, and while such a system is consistent with the eventual application, it is not consistent with the necessary initial task of software development. The most cost-effective way of achieving the latter is with a configuration providing maximum support of fast and powerful peripheral equipment including a disc system, line printer, and console keyboard-display.

Initial wordlength versus trade-off studies performed using masking techniques on a large-scale Digital Equipment Corporation (DEC) PDP-10 facility at DOT-TSC determined the need for a 16-bit wordlength computer. Since a cross-assembler and simulator could be accessed on the PDP-10 facility for development of PDP-11 software, the latter computer was considered. In addition, a PDP-11/15 disc system was available for software development. These considerations were paramount in the decision to acquire a PDP-11/10-AC minicomputer system for the experimental simulator-interface assembly. The configuration consisted of the following components:

(1) KD11B CPU.

(2) 8k 16-bit read/write core memory (900 nanoseconds).

(3) Power fail and restart module.

(4) Bootstrap loader module.

(5) Real-time clock, line frequency.

(6) Teletype interface, line frequency.

(7) Programmer's console.

(8) 5-1/4-inch mounting box and power supply.

(9) ASR-33 teletype and slow-speed paper-tape reader/punch.

(10) Knee-standing cabinet.

(11) Software modules.

The photographs of the simulator-interface and the PDP-11/10-AC minicomputer configuration,including the ASR-33 teletype and slow-speed paper-tape reader/punch,are included in Appendix E.

All software was developed using the PDP-10 and PDP-11/15 disc-system facilities. The assembled program was punched on paper tape for subsequent input to the experimental assembly using the slow-speed reader attached to the teletype. Program input using this technique takes approximately 10 minutes.

The choice of the DEC PDP-11 computer to implement the experimental system should in no way imply a preference for this specific computer in the intended eventual application. As noted previously, software development considerations were paramount in the decision. However, similar considerations will require that one of the eventually deployed systems, or a separate facility, incorporate an above-average minicomputer configuration. This will be necessary for software development and maintenance. It is recommended that it include a disc system and line printer as well as the necessary paper-tape peripheral equipment. The cost of this one-only facility will be small compared to the total deployed-system cost, but must be considered an essential part of the system.

Descriptions of the PDP-11 software developed for the experimental system appear in other sections of this report. A brief description and a listing of the assembly language program appears in Appendix D. Also included in that appendix are sections on an estimate of the processor time requirements for an RVR update and on the program size requirements. Upper limits on the processor time of 0.1 second for integer arithmetic and 0.3 second for the floating-point arithmetic calculations seem to be acceptable for a simultaneous update of RVR based on inputs from n transmissometers. Thus, for a three-runway configuration with three transmissometers per runway, the upper limits on the required processor time are 0.9 second and 2.7 seconds, respectively, for integer and floating-point arithmetic RVR calculations. The time estimates are based on a minimal instruction set which does not include a hardwire multiply and divide capability. With the present trend of lower costs of fabrication, hardwire capability of multiply and divide for both fixed as well as floating-point arithmetic is likely to be available, if so desired, with only a small addition to the total cost of the SDCU configuration. The total size of the simulator software is 1754 memory locations. Thus, it can be inferred that the RVR update processing and associated I/O operations can be carried out with adequate speed and accuracy on a 16-bit minicomputer with 4k memory and memory cycle times of about 1.2 seconds. It is not possible to define the time and size requirements for other visibility system parameters such as SVR, TVR, and ceiling, until the associated systems and calculations are well defined.

4.3 MINICOMPUTER SPECIFICATION

The investigation described in this appendix provides a basis for the specification of a minicomputer configuration to implement the evolutionary system. The specification is written integrally with the interface specification, since the two components are interdependent. The computer specification can be easily met by many low-cost minicomputers currently in the market-place. The dynamic nature of the technology should ensure that even lower-cost mini- or microcomputers will meet the specification in the near future. The specification is not part of this appendix and appears under separate cover.

5. INTERFACE CONFIGURATION AND DESIGN

5.1 INTRODUCTION

This section addresses the topic of communication between external devices and sensors and the minicomputer. The general configuration of an interface to accomplish this task in the current application is delineated and its modular character examined.

The design and mechanization of a simulator-interface is described whereby simulated sensor inputs are interfaced with the software-minicomputer system to verify the conceptual system design and to identify any special hardware/software problems.

5.2 INTERFACE CONFIGURATION

Communication between field-located sensors and the computer and between the computer displays, controls, and switches, takes place through an interface.

The interface consists of registers that receive or transmit information via a bus to the computer. These registers may be either flip-flop storage registers or dynamic signals which are simply gated to the bus during a transfer. In general, registers are both loadable and readable from the bus, but special-purpose interfaces usually contain one-sided registers, that is, either "read only" or "write-only". To maintain the transmission-line characteristics of the bus, special circuits are required to pass signals to and from the bus. The majority of bus signals are received, driven and terminated as shown in Figure 5-1. Information is received from the bus using gates which have a high input impedance and proper logic thresholds. Information transmitted on the bus must be driven with open collector drivers capable of sinking a specified current with a specified collector voltage and with less than a specified output leakage current.

Interface configuration is essentially similar for all contemporary minicomputers, but the detail design and specification is minicomputer-specific. A block diagram of a typical interface for the specific application addressed in this appendix is shown in Figure 5-2. Registers to receive and transmit information are shown for typical parallel and serial I/O data contemplated in this application. Thus, binary counters are shown to receive pulse-rate information, for example, from transmissometers and possibly the ceilometer and slant-visual-range instrumentation. Other registers receive discrete-type information from switches or relays. An example of the latter would be the approach or high-intensity-light-switch setting. Often only a few bits of a 16-bit word will be necessary to transmit information about a discrete switch setting, so that, in general, a single-word register can contain information from more than one source. This approach should be followed whenever possible to economize on interface hardware. Some minicomputer types provide for discrete-bit I/O to simplify control of contacts, relays, etc. Software coding and decoding is relied upon to establish control or status of the devices.

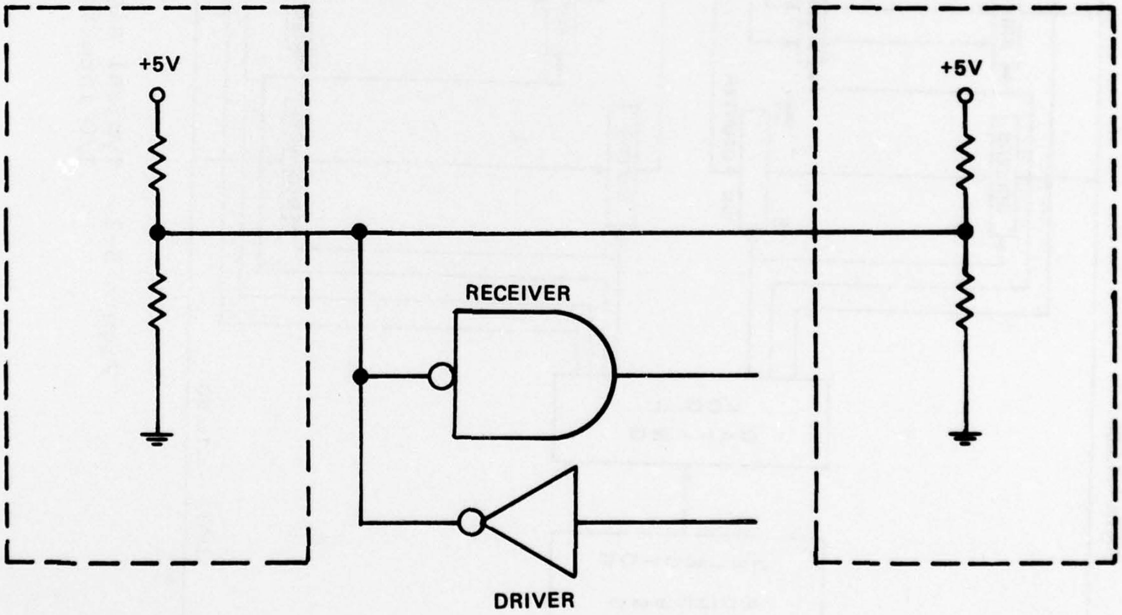

Figure 5-1. Typical bus line.

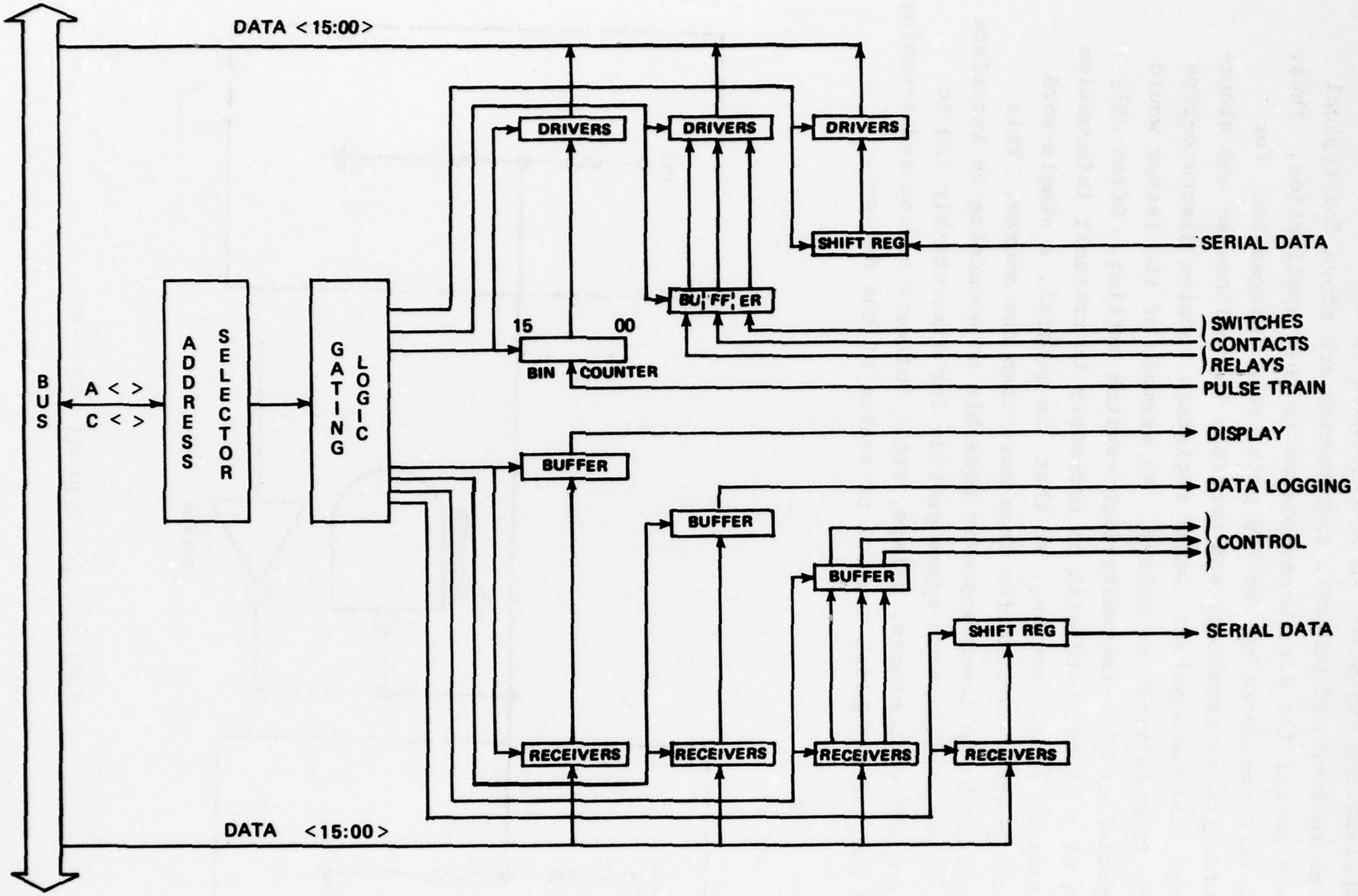

Figure 5-2. Typical signal data converter I/O interface configuration.

Output registers store specific information strobed from the computer. The information may be intended to display, for example, the runway visual range, slant-visual range and ceiling or intended to control external devices such as the intensity of the runway lights or to sound an alarm when a specific event takes place. Data logging is another output function. As before, a full 16-bit word may contain information intended for more than one destination. Definition and specification of the output interface essentially ends at the register. Local displays and controls are designed to receive their information as parallel data directly from these registers. Transmission of register information to distant locations (for example, remote displays) requires a serial data transmission. Some minicomputers have serial data I/O channels, in addition to the common parallel channels, to facilitate the transmission of data to or from remote devices. In general, however, the task of converting data from parallel- to serial-bit format and providing an appropriate gated clock signal for serial I/O operations is considered part of the interface function.

Associated with each interface or device register is a unique address by which communication with the computer is possible. When information in a particular register is required by the computer, the address of that register is put on the bus and decoded by another major interface element, the address selector. The latter transmits control signals to the addressed register which gates the requested information onto the bus via the data lines. Similarly, information is transferred from the computer to specified interface output registers.

5.3 MODULAR INTERFACE DESIGN

From the foregoing description, it is possible to see the potential for modular interface design. A field installation would require multiple combinations of the five types of registers discussed in Subsection 5.2, namely binary counters to register pulse-rate data, parallel-word input registers containing discrete switch, contact, or relay data, parallel-word output registers to transmit local display, data logging or control information, and shift registers to transmit and receive serial data; the latter required only for communication with remote devices.

Each of the five types of I/O interface would contain an associated address selector for address decoding and either receiver or driver networks. Each would contain a convenient number of (identical) registers or words, probably two, three, or four, depending upon the interface type. For example, three would be a convenient number for the pulse-rate input module, since three transmissometers will be associated with each runway (at touchdown, midpoint, and rollout locations). The I/O interface cards would plug into a common, multi-slot chassis with common connection to the bus.

A modular approach to interface design is recommended so that the size and capability of a typical system can be matched to the particular requirements of the airport installation. It is consistent with the modular character of the minicomputer and software design. If airport requirements expand, the system can grow to meet the needs with the addition of the appropriate modules in either the interface or minicomputer or both.

5.4 *RVR SIMULATOR-INTERFACE DESIGN*

The design of the RVR simulator-interface is instructive because it contains examples of all of the register types that will be required in the field installation. The experimental interface is designed to accept inputs from simulated sensors and transmit this data, upon request, to the minicomputer. An output register accepts data from the computer for subsequent visual display of RVR. The simulated sensors produce signals of the type specified for actual field-installed sensors. They include pulse-train signals of the type and bandwidth required from transmissometers and also possibly the ceilometer and slant-visual-range instrumentation; signals from discrete switch settings or relays representing signals from the runway high-intensity light setting switch or background luminance sensor or runway selector; binary-coded signals from a controller-selected decimal panel switch representing an "alert" RVR value or from a serial-loaded shift register representing the interface for a serial transmission from a remote sensor. All I/O signal levels are consistent with interface logic, namely, 5 volts.

A block diagram of the simulator-interface is shown in Figure 5-3. A detailed schematic of the simulator-interface is shown in Figure 5-4, and views of its three components are shown in Figures 5-5 through 5-7. Figure 5-5 shows the front control panel of PDP-11/10-AC minicomputer. Figure 5-6 shows the ASR-33 teletype and slow-speed paper-tape reader/punch. Figure 5-7 shows the front panel of the simulator-interface showing the switches controlling various simulated-sensor inputs and the RVR digital display. The function of the switches is briefly described below. A ten-position switch for transmissometer

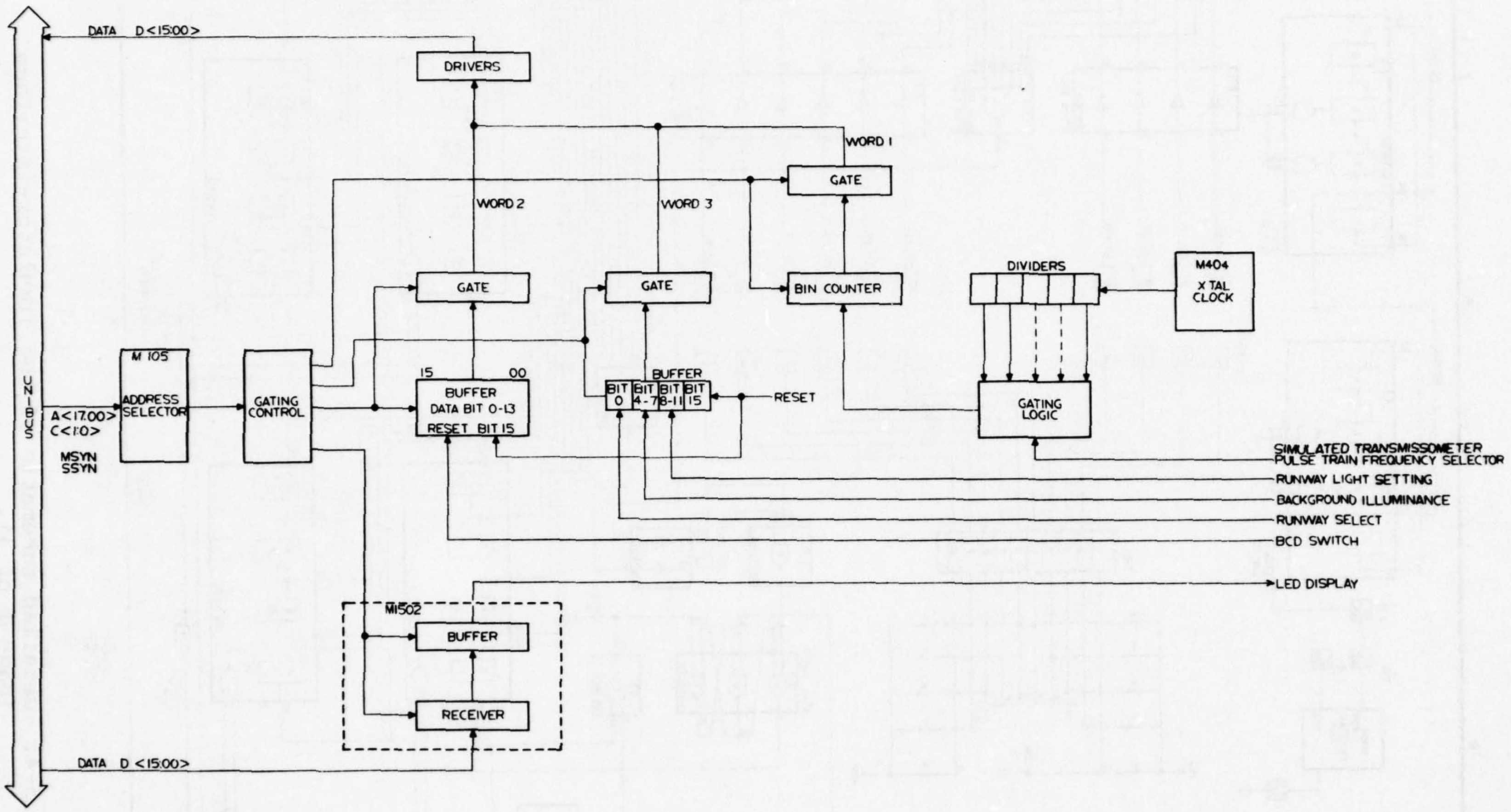

Figure 5-3. Block diagram of the simulator-interface.

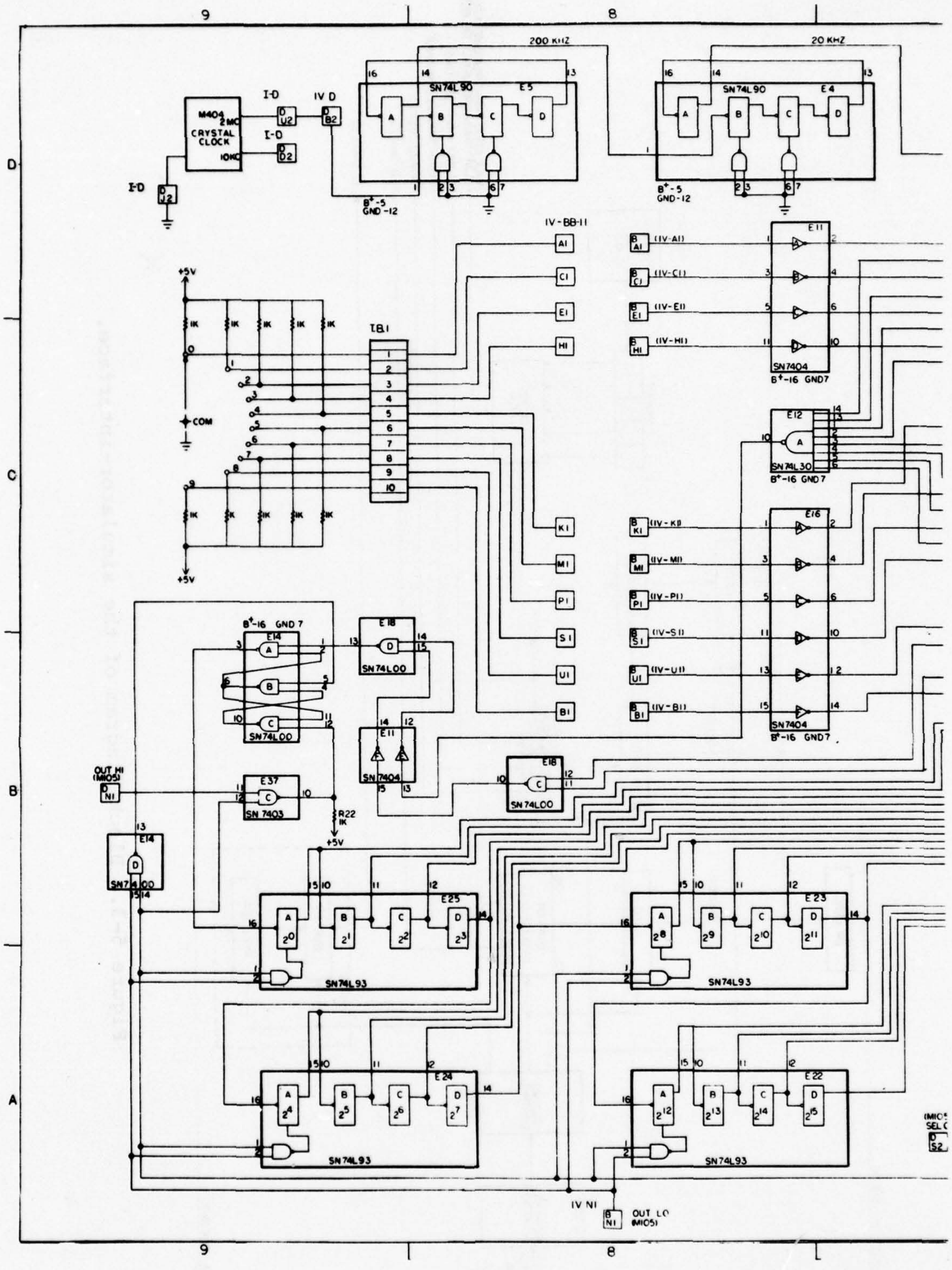

Figure 5-4. Detailed schematic of the simulator-interface (page 1 of 4).

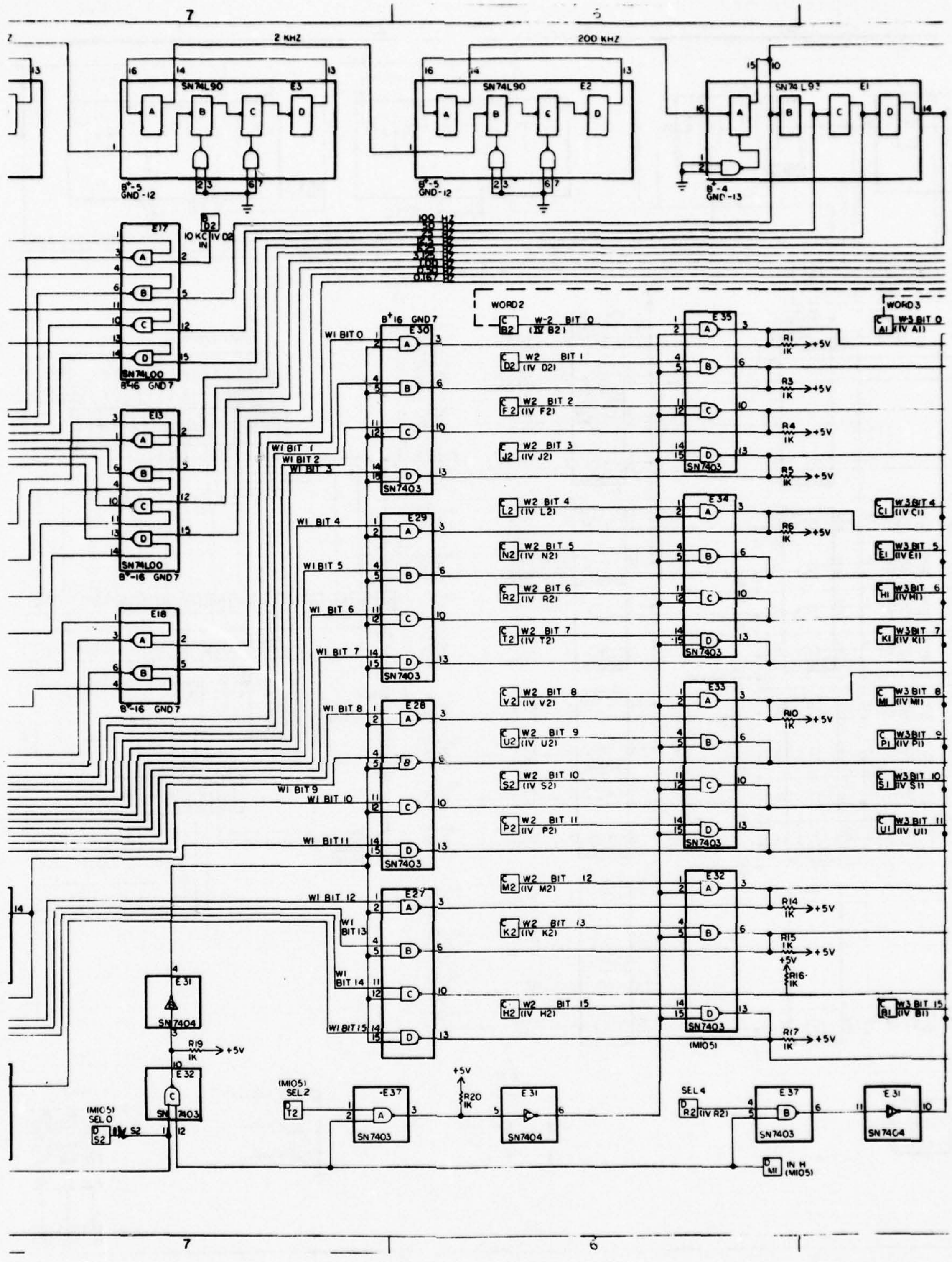

Figure 5-4. Detailed schematic of the simulator-interface (page 2 of 4).

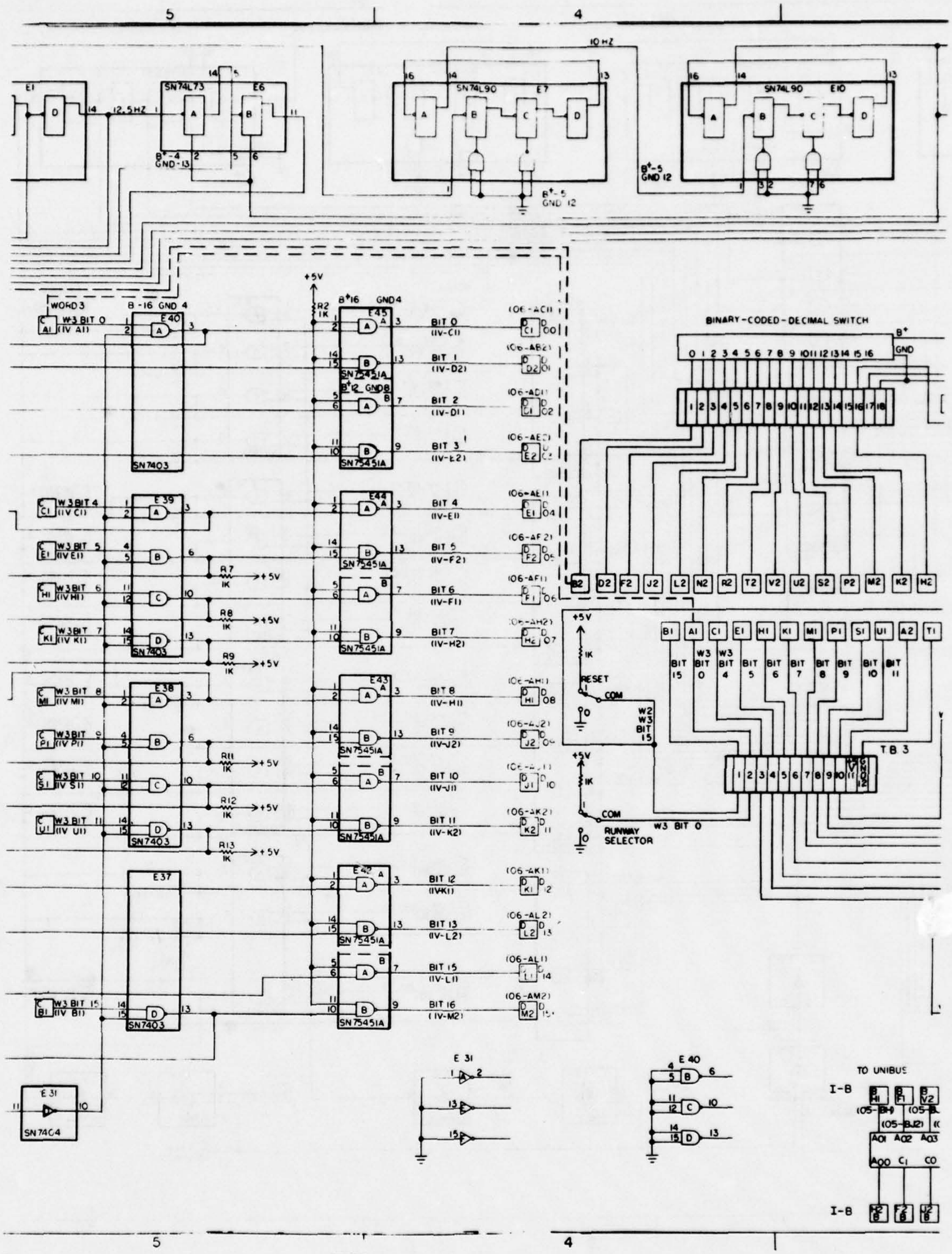

Figure 5-4. Detailed schematic of the simulator-interface (page 3 of 4).

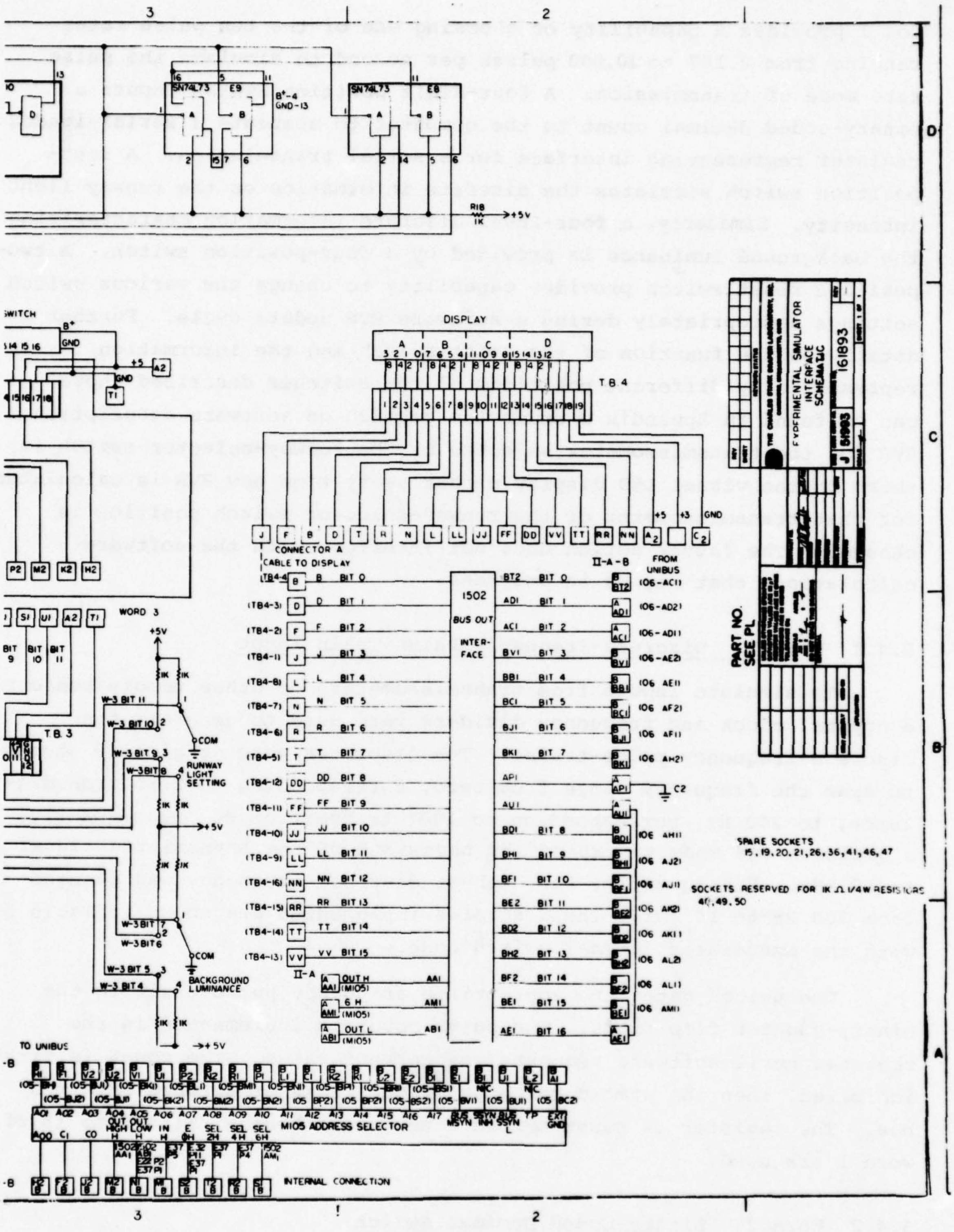

Figure 5-4. Detailed schematic of the simulator-interface (page 4 of 4).

No. 1 provides a capability of choosing one of the ten pulse rates ranging from 0.167 to 10,000 pulses per second to simulate the pulse rate mode of transmission. A four-digit position switch inputs a binary-coded decimal count to the computer to simulate a serial-loaded register representing interface for a serial transmission. A four-position switch simulates the discrete information on the runway light intensity. Similarly, a four-level discrete information characterizing the background luminance is provided by a four-position switch. A two-position reset switch provides capability to change the various switch settings appropriately during a software RVR update cycle. Further details on the function of the reset switch and the information represented by different positions of the switches described above can be found in Appendix D under the section on software description. RVR for the transmissometer selected by the runway-selector switch is shown on the visual LED display either every time new RVR is calculated for that transmissometer or the runway-selector switch position is changed. The latter action does not interfere with the software calculations that may be in progress.

5.4.1 Word 1: Discrete-Frequency Pulse-Train Input

To simulate inputs from transmissometers or other remote sensors, a crystal clock and frequency dividers were used to generate ten discrete-frequency pulse-trains. The discretes were originally chosen to span the frequency range from zero, corresponding to zero transmittance, to 200 Hz, corresponding to 100% transmittance. Subsequently, a decision was made to expand the bandwidth of the transmitted signal to 10 kHz. Consequently, the highest discrete frequency was changed from 200 Hz to 10 kHz. The discretes implemented are shown in Table 5-1 with the associated decimal switch code.

The switch gates the appropriate frequency pulse-train to the binary-counter flip-flops. The pulse count is incremented in the register until software requests the current value. The count is first inhibited, then the static contents of the register strobed onto the bus. The register is reset before a new count begins. Bits 0 to 15 of word 1 are used.

5.4.2 Word 2: Binary-Coded Decimal Switch

This serial-loaded binary work register simulates the interface for an alternative means of transmitting data from remote sensors,

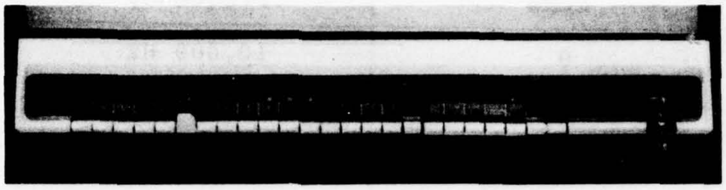

Figure 5-5. Front control panel of the PDP-11/10-AC minicomputer of the simulator-interface minicomputer configuration.

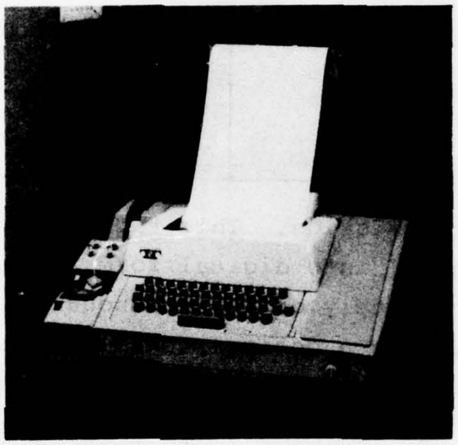

Figure 5-6. ASR-33 teletype and slow-speed paper-tape reader/punch.

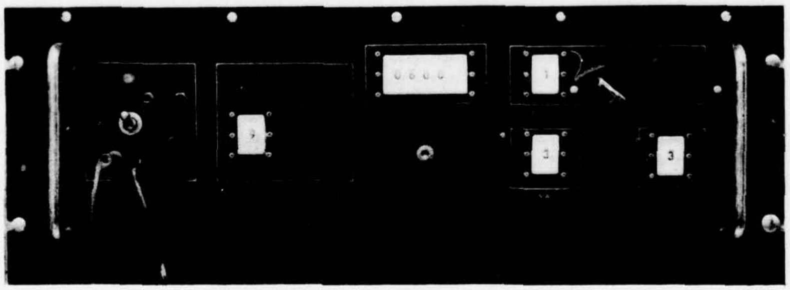

Figure 5-7. Front control panel of the signal simulator bearing switches controlling the simulated sensor inputs to the minicomputer and the visual RVR digital display.

TABLE 5-1. PULSE-TRAIN DISCRETE-FREQUENCY CODE

Code	Frequency
0	10,000 Hz
1	100
2	50
3	25
4	12.5
5	6.25
6	3.125
7	1.000
8	0.500
9	0.167

namely, serial data transmission. This technique requires that the sensor output be converted into digital form, coded, and transmitted serially, either synchronously or asynchronously, to the interface. The register also simulates a decimal console-panel switch into which the controller could load an "alert" RVR value. The decimal value is coded internally into binary form before being gated to the bus. Bits 0 to 15 of word 2 are used.

5.4.3 Word 3: Discrete Switch, Relay, or Control Settings

This register contains information on discrete switch settings or control relay positions that must be communicated to software. The specific functions simulated were the runway-light-intensity setting (bits 8 to 11), the background-luminance setting (bits 4 to 7), the runway selector (bit 0), and the reset switch (bit 15). The latter is unique to the simulator-interface, being reset whenever a change is made to word 1 or 2. Bits 1, 2, 3, 12, 13, and 14 of word 3 are unused.

5.4.4 Word 4: Output Register

This register receives output signals from the computer that are destined for local or remote display, to control switches or relays, or for data logging. The flip-flop register of the simulator-interface drives a local four-digit LED display of RVR. All 16 bits of the word are used.

5.5 IMPLEMENTATION OF THE SIMULATOR-INTERFACE

This subsection describes the basic assumptions and definitions for the simulator-interface, and the ground rules under which the combined software/hardware must operate. A description of the mechanization is also given. A schematic of the simulator-interface is shown in Appendix E.

A typical sequence of operations that must occur is indicated in Table 5-2.

The interface contains a DEC M105 Address Selector, an M1502 Bus Output Interface, and an M404 Crystal Clock. All other functions, including input registers, are implemented on a blank wire-wrappable module. This card and the DEC cards plug into a BB11 module connector. The whole subassembly is mounted in a chassis and connected to the computer via a BC11A bus cable. Only 5-volt power in needed for the interface, and this is supplied by an external supply.

An 18-bit address A (17:00) is decoded. A (17:13) must all be ones and set by software. A (12:03) is determined by jumpers on the M105 card. When the jumper is "in", the computer will look for a zero on that address line. The addresses to be used are 764000 to 767777. So if addresses 764000, 764002, 764004, and 764006 are to be used, jumpers are placed in bits 3, 4, 5, 6, 7, 8, 9, 10, and 12. The M105 controls up to four addresses. A00, A01, A02, C00,and C01 are used for control.

Note that the address supplied on the bus is that of the even-numbered location and the next higher odd location is selected as well. A02 and A01 provide a coding array for the four selected addresses. A00 is for byte operation. A DATI to 764000 transfers data to locations 764000 and 764001 in two bytes. A DATOB to location 764006 loads only location 764006.

It is important to bear in mind that the sequence of operations is critical; otherwise the data may be lost or will be in error. Referring to the chart, assume that the computer is ready to start a read/write sequence. Step 1 must occur first. This step clears the 16-bit binary counter and sets a clock-enable flip-flop. This allows the 16-bit counter to be clocked at the selected rate determined by the ten-position selector switch. The period of counting is now set by the computer, and must be small enough so the counter will not overflow. Immediately after this predetermined period, step 2 must

TABLE 5-2. TYPICAL SEQUENCE OF I/O OPERATIONS FOR THE SIMULATOR-INTERFACE

STEP NO.	OPERATION	ADDRESS BITS					COMMENTS
		A02	A01	A00	C01	C00	
1	Initialize—Clears 16-bit counter and sets clock-enable flip-flop	0	0	0	1	1	DATOB—Sets Select 0 and Out Low to ones Data bits—not applicable Bus address = 764000
2	Resets clock-enable flip-flop, prevents further counting	0	0	1	1	1	DATOB—Sets Select 0 and Out Hi to ones Data bits—not applicable Bus address = 764001
3	Reads transmissometer counter into computer	0	0	0	0	0	DATI—Sets Select 0 and INH to ones Strobes word 1 into computer Bus address = 764000
4	Reads preset transmissometer data into computer	0	1	0	0	0	DATI—Sets Select 2 and INH to ones Strobe word 2 into computer Bus address = 764002
5	Reads word 3 into computer	1	0	0	0	0	DATI—Sets Select 4 and INH to ones Strobes word 3 into computer Bus address = 764004
6A	Output runway visual range to display	1	1	0	1	1	DATOB—Sets Select 6 and Out Low to ones Puts Low Order byte to display Bus address = 764006
6B	Output runway visual range to display	1	1	1	1	1	DATOB—Sets Select 6 and Out Hi to ones Puts High Order byte to display F[illegible] address = 764007

occur. This will clear the clock-enable flip-flop inhibiting any further counting. The binary counter, however, will retain its last value until it is cleared again by repeating step 1. Step 1 should not occur until the data is read into the computer.

After step 2 is performed, steps 3, 4, and 5 may be performed in any sequence. The three words are now stored in the computer. Steps 6A and 6B should be done sequentially. Since the data to the display is output in two bytes, the time delay between the two DATOB output instructions will be small enough so that the eye will not see it.

Word 3 does not use all 16 bits. Bit 0 is either a 1 or 0, and is set by the runway-selector switch. Bits 1,2, and 3 are not used. Bits 4, 5, 6, and 7 are the output of the four-position background-luminance switch. Only one of the four bits will be enabled at any time. Bits 8, 9, 10, and 11 are the outputs of the four-position runway-light-intensity setting switch. Again,only one of the four bits will be enabled at any one time. Bits 12, 13, and 14 are not used. Bit 15 is the output of a reset switch. This reset switch is set while changing the front panel switches such as the BCD selector switch or the transmissometer frequency selector switch.

It is apparent from a study of the simulator-interface schematic in Appendix E that a common set of drivers is employed for words 1, 2, and 3. This is possible because only one word at a time can be addressed and driven onto the bus. Control signals from the address selector gate the appropriate word to the drivers. Similarly, this approach would be followed in the design of the modular interface for the field installation. Each individual multi-word interface card would employ a common set of drivers or receivers.

5.6 CHARACTERIZATION OF THE INTERFACE SENSOR INPUTS

Previous sections of this subsection have described the configuration of an interface to communicate between sensors or devices and the computer. It is clear that the interface-software system is very flexible so that a variety of alternative input signal formats can be considered as candidate specifications. This flexibility is important, indeed it is a prime characteristic of such a hardware/software system, in that it provides freedom for the unconstrained design of new sensors and modification of existing sensors to take full advantage of new technology. This is also true in the selection of sensor data transmission technique.

The modular construction envisioned for the field-interface installation provides for a multiplicity of I/O signal formats, thus the selection of a format for a particular sensor will not be constrained by interface design. Consideration of the type of information the signal conveys and its time domain characteristics, as well as transmission technology considerations, will be determining factors.

Input signals to current SDC systems and anticipated additional inputs to future visibility-monitoring configurations are reviewed in Subsection 5.6 with respect to their time domain, signal format, and transmission characteristics.

5.6.1 Transmittance Measurement Sensors

RVR transmissometers, background-luminance sensors, anticipated TVR, SVR, and ceilometer sensors all fall into this category. The signals from these sensors are characterized by an inherent spatial integration. Further processing to provide a useful visibility measurement includes temporal integration. Currently, the transmission from remote transmissometers has a pulse-train signal form, the pulse rate being a measure of transmittance. The temporal integration for these signals simply involves a count of the pulses over a given period of time, a function which can be easily and simply provided by suitable hardware counting logic located in the SDC I/O interface. The pulse counting can be accomplished by the computer software also, however at an expense in the form of increased computational time and memory size requirements. Moreover, the increased cost of the necessary hardware logic modules to interrupt the software program on the arrival of a new pulse more than offsets the savings that result from having dispensed with the hardware counters. These considerations tend to rule out the pulse counting by the software when the sensor data is transmitted using pulse rate modulation. The 20-meter baseline transmissometer under development at TSC uses a similar signal format but with bandwidth increased to 10 kHz. Advanced semiconductor technology drivers transmit pulses up to 10 MHz over very long distances using a twisted-pair line. The latter is terminated with a receiver that presents the pulse train at proper logic levels to the interface. It is recommended that the background-luminance sensor under development at TSC and TVR sensors transmit data in a similar manner to the 20-meter base transmissometer, using a common bandwidth for the transmissivity measurement.

SVR and ceilometer instrumentation is currently in the experimental stage. However, the extent of the calculations, including deconvolution, known to be involved in the reduction of a measurement of backscattering from a laser pulse, would appear to preclude the use of the central minicomputer for this data processing. Both analog and digital preprocessing of the backscattering data require further investigation.

Digital processing has the advantage in that a dedicated minicomputer could handle data processing and instrument control. The signal format and transmission of a transmittance measurement from either the SVR or ceilometer sensors need not be specified at this time. Commonality with other transmittance sensors would suggest a similar pulse-train signal format. However, the discrete measurement nature of the new sensor might make a BCS (or similar) serial transmission more convenient. The cost or other impact on interface design is negligible.

5.6.2 Status of Switches and Relays

Relay and switch positions providing the status of high-intensity runway lights, approach lights, or discrete-level background luminance appear as discrete (static) logic levels at the interface. This is a straightforward procedure for local (parallel) transmission of data, as was demonstrated on the design of the simulator-interface. Only two lines are necessary to transmit information from a four-position switch; three lines from an eight-position switch. When switches or relays are remotely located, a serial data transmission may be necessary.

Data must be conditioned by appropriate line drivers and receivers, presenting the data at correct logic levels for loading into the shift-register on the appropriate interface card. Gated clock signals must be provided by the minicomputer or an external reference. Serial data transmission is typically at a pulse rate of 100 to 1000 kHz.

An alternative method of transmitting remote switch and relay data is by frequency multiplexing. This technique involves transmitting a discrete frequency pulse-train corresponding to each switch, relay, or control position. The interface to accept this data is identical to that provided for pulse rate information from the transmissometers. Appropriate line drivers and receivers would be required as with all remote data transmission. The design of the discrete frequency pulse-train transmitter would be similar to the pulse-train simulator detailed in a previous section.

5.7 INTERFACE SPECIFICATION

The detailed design of an interface assembly depends upon the specific minicomputer choice. For this reason, specification of the interface has been made integral with that of the minicomputer to implement the eventual evolutionary system (see Subsection 4.3).

APPENDIX A

ITERATIVE ALGORITHMS FOR RVR COMPUTATION

A.1 INTRODUCTION

An investigation is made of the performance of different iterative algorithms to solve a nonlinear equation $y = f(x)$ for its zero. All iterative algorithms considered are single point in character and utilize the information on the value of the function, $f(x)$, and its higher derivatives at a given point to arrive at the next guess. First, the Newton-Raphson method is investigated, which utilizes the value of the function and its slope, and then three different methods are considered, all utilizing higher-order information up to second derivatives of the function.

Let α be the zero of $y = f(x)$, i.e., $f(\alpha) = 0$.

A.2 NEWTON-RAPHSON METHOD

The Taylor series expansion of $y = f(x)$ about point x_i is given by

$$y = f(x_i) + (x - x_i)f'(x_i) + \frac{1}{2}(x - x_i)^2 f''(p), \quad x < p < x_i \tag{A-1}$$

Since $f(\alpha) = 0$, we have

$$0 = f_i + (\alpha - x_i)f_i' + \frac{1}{2}(\alpha - x_i)^2 f''(p), \tag{A-2}$$

dropping the arguments.

Equation (A-2) suggests the following iteration formula:

$$x_{i+1} = x_i - \frac{f_i}{f_i'}, \tag{A-3}$$

which is the familiar Newton-Raphson method. Substituting for x_i in (A-2) and using (A-3),

$$0 = f_i + \left(\alpha - x_{i+1} - \frac{f_i}{f_i'}\right)f_i' + \frac{1}{2}(\alpha - x_i)^2 f''(p),$$

or

$$\varepsilon_{i+1} = -\frac{1}{2}\frac{f''(p)}{f_i''}\varepsilon_i^2 \qquad \text{(A-4)}$$

where $\varepsilon_i = \alpha - x_i$ is the error at stage i. Thus, Newton-Raphson has a second order of convergence.

A.3 HIGHER-ORDER METHODS UTILIZING SECOND DERIVATIVE

Let $y = f(x)$ have an inverse $x = g(y)$ in the neighborhood of a root α of $f(x) = 0$. The Taylor series expansion of $g(y)$ about a point y_i is given by

$$x = g(y) = g(y_i) + (y - y_i)g'(y_i) + \frac{1}{2}(y - y_i)^2 g''(y_i) + \frac{1}{6}(y - y_i)^3 g'''(p), \qquad \text{(A-5)}$$

where p is between y and y_i. Since $\alpha = g(0)$, we have:

$$\alpha = x_i - f_i g_i' + \frac{1}{2}f_i^2 g_i'' - \frac{1}{6}f_i^3 g'''(p), \qquad \text{(A-6)}$$

where $y_i = f(x_i) = f_i$.

It is easy to deduce from the inverse relationship of the functions $y = f(x)$ and $x = g(y)$, that:

$$f_i' g_i' = 1. \qquad \text{(A-7)}$$

By successively differentiating (A-7), we evaluate:

$$g_i'' = \frac{-f_i''}{(f_i')^3} \qquad \text{(A-8)}$$

and

$$g_i''' = \left(\frac{-1}{(f_i')^3}\right)\left(\frac{f_i'''}{f_i'}\right) - \frac{3f_i''^2}{(f_i')^2}. \qquad \text{(A-9)}$$

A.4 METHOD 2

Equation (A-6) suggests the following iteration formula:

$$x_{i+1} = x_i - \frac{f_i}{f_i'}\left(1 + \frac{1}{2}\,\frac{f_i}{f_i'}\cdot\frac{f_i''}{f_i'}\right), \qquad \text{(A-10)}$$

which is the same as what has been referred to as Method 2.

Subtracting (A-10) from (A-6), we have the following expression for error at each iteration:

$$\varepsilon_{i+1} = -\frac{1}{6}g'''(p)f_i^{\,3},$$

since

$$\begin{aligned} f_i &= f(x_i) = f(x_i) - f(\alpha) = (x_i - \alpha)f'(q) \\ &= -\varepsilon_i f'(q), \text{ with } q \text{ between } \alpha \text{ and } x_i \end{aligned}$$

$$\varepsilon_{i+1} = \left(\frac{1}{6}f'(q)g'''(p)\right)i^3. \qquad \text{(A-11)}$$

If the root α is simple, the expression in brackets is bounded in some interval of α. Thus, the order of the iteration formula (A-10) is three.

A.5 HALLEY'S METHOD

Consider the iteration formula

$$x_{i+1} = x_i - f_i g_i' + \frac{1}{2}f_i^{\,2}g_i'' = x_i - u_i\left(f_i'g_i' - \frac{1}{2}f_i f_i' g_i''\right).$$

Our object is to approximate (A-1) by the rational formula:

$$x_{i+1} = x_i - \frac{P_0}{1 + Q_1 u_i}\cdot u_i,$$

where

$$u_i = \frac{f_i}{f_i'},$$

and choose P_0 and Q_1, such that

$$f_i'g_i' + \frac{1}{2}f_i f_i' g_i'' = 1 + \frac{1}{2}u_i\,\frac{f_i''}{f_i'}$$

and

$$\frac{P_o}{1 + Q_1 u_i}$$

have as many derivatives equal as possible at $u_i = 0$. We would like to choose two constants at our disposal, P_o and Q_1, such that

$$\left(1 + \frac{1}{2} u_i \frac{f_i''}{f_i'} - \frac{P_o}{1 + Q_1 u_i}\right),$$

and its first derivative with respect to u is equal to zero at $u_i = 0$. Consider

$$\left(1 + \frac{1}{2} u_i \frac{f_i''}{f_i'}\right) - \frac{P_o}{1 + Q_1 u_i} = \frac{\sum_{j=0}^{\infty} H_j u_i^j}{1 + Q_1 u_i} .$$

This requirement is met if $H_o = H_1 = 0$. Then:

$$P_o = 1 \quad \text{and} \quad Q_1 = -\frac{1}{2} \frac{f_i''}{f_1'}$$

Thus, we arrive at Halley's iteration formula

$$x_{i+1} = x_i - u_i \frac{1}{\left(1 - \frac{1}{2} u_i \frac{f_i''}{f_i'}\right)} . \qquad \text{(A-12)}$$

Subtracting (A-12) from (A-6), we get the expression for the error:

$$\varepsilon_{i+1} = -\frac{1}{6} g'''(p) f_i^3 - \frac{1}{2} \frac{f_i''}{(f_i')^4} \frac{1}{\left(1 - \frac{1}{2} u_i \frac{f_i''}{f_i'}\right)} \cdot f_i^3 .$$

Now $f_i = -\varepsilon_i f'(q)$ with q between α and x_i as explained earlier. Thus,

$$\varepsilon_{i+1} = f'(q) \left[\frac{1}{6} g'''(p) + \frac{1}{2} \frac{f_i''}{(f_i)^4} \frac{1}{\left(1 - \frac{1}{2} u_i \frac{f_i}{f_i'}\right)}\right] \varepsilon_i^3 . \qquad \text{(A-13)}$$

If the root is simple, the expression in outer brackets is bounded in some interval of α. Thus, the order of the iteration formula (A-12) is three.

A.6 MODIFIED NEWTON-RAPHSON METHOD

Instead of considering the function f(x), consider the function $u(x) = f(x)/f'(x)$. Both u(x) and f(x) have the same zeros. Applying the Newton-Raphson to find a zero of u(x), we have the following iteration formula:

$$x_{i+1} = x_i - \frac{u_i}{u_i'} = x_i - u_i \frac{1}{\left(1 - \frac{u_i f_i}{f_i'}\right)} . \qquad \text{(A-14)}$$

This is also known as the modified Newton-Raphson method. This method is particularly useful in case of functions with multiple roots. The order of convergence of Newton-Raphson method is equal to one, when the function has a zero of multiplicity greater than 1. It may be noted that the second-order convergence of the Newton-Raphson method can still be maintained in such cases, by considering finding the zero for u(x) instead of f(x), since u(x) has a zero of multiplicity 1, irrespective of the multiplicity of the zero of f(x). The order of convergence for this method near a zero is the same as that for the Newton-Raphson method.

A.7 COMMENTS ON THE ORDER OF CONVERGENCE

We have considered four iterative methods. It is seen that the Newton-Raphson and modified Newton-Raphson methods exhibit second-order convergence near zero, whereas the other two methods, Method 2 and Halley's method, exhibit third-order convergence. The modified Newton-Raphson method retains the second-order convergence in case of a function with multiple roots. However, since this method uses the information on the second derivative of the function slightly improved convergence is likely to result when used for a function with simple roots.

APPENDIX B

COMPUTATION OF LOGARITHM

The logarithm function $\log_{10}(x)$ is calculated in fixed-point arithmetic as follows:

(1) Integer x is normalized and expressed as

$x = F \cdot 2^b$, such that $1/2 \le F \le 1$ and $b \le N-1$

N = number of bits in the word used for representation of and integer (includes sign bit)

(2) Calculate $\log_{10} x$ as follows:

$$\log_{10} x = \log_{10} F + b \log_{10} 2$$

where

$$\log_{10} F = (C_1 Z + C_3 Z^3 + C_5 Z^5) \log_{10} 2 - 1/2 \log_{10} 2$$

$$C_1 = 2.8853913$$

$$C_3 = 0.96147063$$

$$C_5 = 0.59897865$$

$$\log_{10} 2 = 0.30102999$$

$$Z = \frac{F - \sqrt{0.5}}{F + \sqrt{0.5}}$$

$$\sqrt{0.5} = 0.70710678$$

In the case of the subroutine LOG in the arithmetic package described in Appendix D, argument, X, is available as an integer in register R_0, and $\log_{10}$ (argument) is available on return from the program in double precision in registers R_0 and R_1 with associated scale factor in register R_2.

A similar software program was written on a 24-bit wordlength machine with provisions to simulate varying wordlengths. Figure B-1 shows the plot of $-\log_2\varepsilon$ versus the wordlength, N, where ε is an average computed from the errors of the logarithm function computed for ten integers of varying magnitudes. Thus, the relationship $\varepsilon \simeq 1/2^{N-5}$ can serve as a rough measure of the order of accuracy available from the logarithm function, which is computed as described in this appendix.

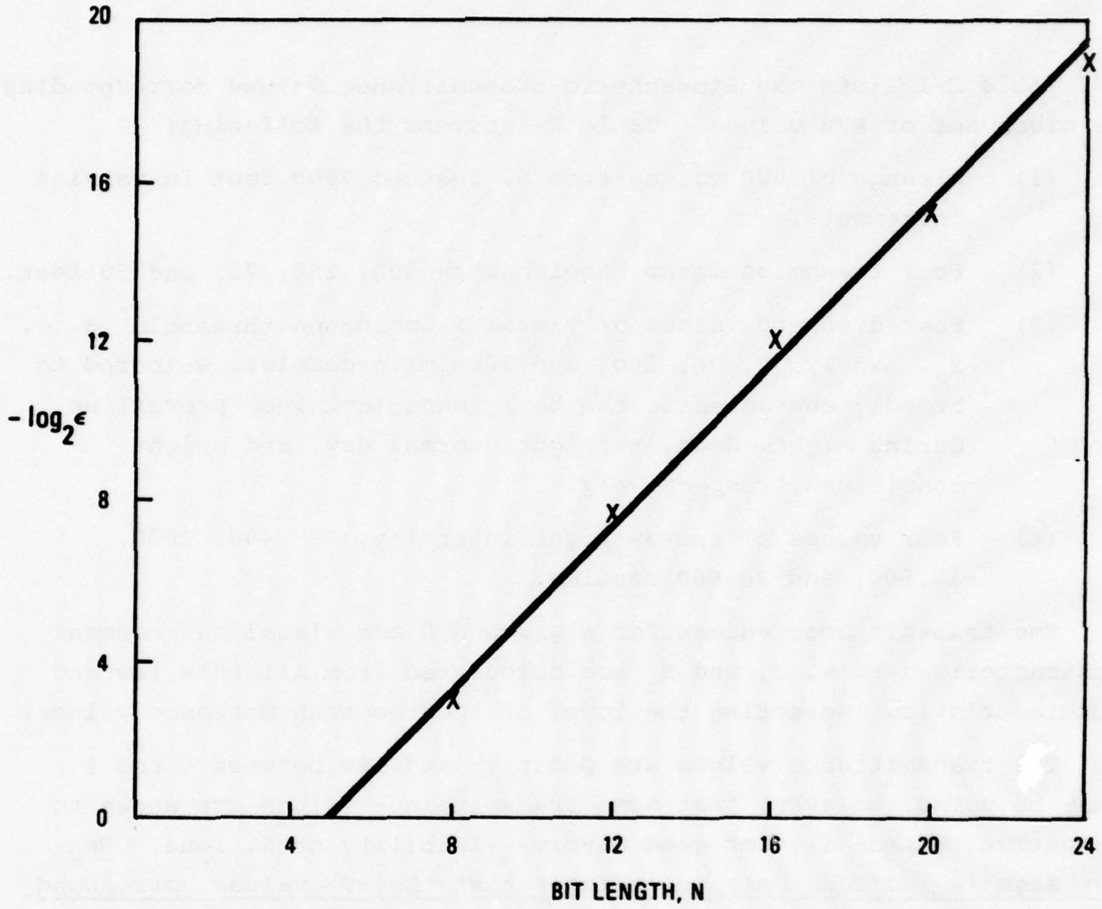

Figure B-1. Plot of $-\log_2\varepsilon$ vs N, showing the dependence of ε, the computation error for the fixed-point algorithm and N, bit length of the computer word.

APPENDIX C

ATMOSPHERIC TRANSMITTANCE FOR RVR RANGE 50 TO 5900 FEET

Table C-1 lists the atmospheric-transmittance values corresponding to a given set of RVR values. Table C-1 covers the following:

(1) A range of RVR values from 50 feet to 5900 feet in varying increments.

(2) Four transmissometer baselengths—500, 250, 75, and 50 feet.

(3) Four discrete values of visual illuminance threshold[*] s, c, E_t, namely, 2, 26, 260, and 2600 mile-candles, selected to broadly characterize the background luminance prevailing during night, dawn, twilight, normal day, and bright conditions, respectively.

(4) Four values of runway-light intensity, I - 400, 2000, 10,000, and 20,000 candles.

The transmittance values for a given RVR and visual environment as characterized by s, c, and E_t are calculated from Allard's law and Koschmieder's law, selecting the lower of the two transmittance values.

The transmittance values are positive and lie between 0 and 1. It may be noted, however, that some transmittance values are shown to be negative, especially for good daytime visibility conditions. <u>The minus sign is included only to indicate that the RVR values correspond to the contrast visibility as projected by Koschmieder's law.</u>

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[*] As recommended by ICAO All Weather Operational Panel (AWOP Report, IV-WP-213).

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 1 of 16)

BASE LINE 500.00000

ET= 2.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000000	.000000000	.000000000	.000000000
100.0	.000000000	.000000000	.000000000	.000000000
150.0	.000000000	.000000000	.000000000	.000000000
200.0	.000000000	.000000000	.000000000	.000000000
250.0	.000000000	.000000000	.000000000	.000000000
300.0	.000000000	.000000000	.000000001	.000000010
350.0	.000000001	.000000002	.000000022	.000000222
400.0	.000000016	.000000038	.000000281	.000002100
450.0	.000000151	.000000326	.000001951	.000011663
500.0	.000000897	.000001794	.000008968	.000044838
550.0	.000003782	.000007102	.000030675	.000132497
600.0	.000012375	.000022049	.000084307	.000322357
650.0	.000033382	.000056894	.000196217	.000676717
700.0	.000077488	.000127132	.000401347	.001267023
750.0	.000159675	.000253468	.000741145	.002167121
800.0	.000298930	.000461014	.001260579	.003446881
850.0	.000517446	.000777931	.002004934	.005167242
900.0	.000839478	.001233810	.003016929	.007377034
950.0	.001290092	.001858051	.004334475	.010111497
1100.0	.003651808	.005004259	.010400481	.021615588
1200.0	.006267910	.008366656	.016360231	.031990935
1300.0	.009847250	.012855700	.023874283	.044336862
1400.0	.014442376	.018499047	.032868623	.058400108
1500.0	.020058797	.025272501	.043215369	.073897241
1600.0	.026664214	.033113163	.054755631	.090543424
1700.0	.034198639	.041932143	.067317266	.108070182
1800.0	.042583726	.051625361	.080727487	.126234996
1900.0	.051730562	.062081989	.094821123	.144825344
2000.0	.061545745	.073190638	.109445532	.163659243
2100.0	.071935856	.084843627	.124463111	.182583733
2200.0	.082810575	.096939708	.139752159	.201472301
2300.0	.094084719	.109385661	.155206676	.220221846
2900.0	.166191306	.187288032	.247184990	.326237714
3400.0	.226747572	.251079793	.318127688	.403079931
3900.0	.284082032	.310482663	.381635612	.469094599
4400.0	.336867263	.364474175	.437617994	.525440544
4900.0	.384783789	.412984843	.486695783	.573562901
5400.0	.427993336	.456362714	.529699545	.614821497
5900.0	.466863054	.495108661	.567460020	.650384250

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 2 of 16)

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BASE LINE       500.00000
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                          ET=      26.00000
      RVR     I=  20000.0     I=  10000.0      I=     2000.0     I=      400.0

     50.0     .000000000      .000000000      .000000000      .000000000
    100.0     .000000000      .000000000      .000000000      .000000000
    150.0     .000000000      .000000000      .000000000      .000000000
    200.0     .000000000      .000000000      .000000000      .000000000
    250.0     .000000000      .000000000      .000000001      .000000021
    300.0     .000000001      .000000003      .000000051      .000000741
    350.0     .000000032      .000000087      .000000868      .000008646
    400.0     .000000390      .000000927      .000006934      .000051845
    450.0     .000002611      .000005640      .000033720      .000201615
    500.0     .000011658      .000023316      .000116578      .000582889
    550.0     .000038937      .000073119      .000315831      .001364214
    600.0     .000104910      .000186928      .000714740      .002732898
    650.0     .000240097      .000409212      .001411293      .004867280
    700.0     .000484070      .000794200      .002507229      .007915134
    750.0     .000882806      .001401367      .004097623      .011981523
    800.0     .001485199      .002290490      .006263033      .017125408
    850.0     .002339513      .003517240      .009064854      .023362517
    900.0     .003490334      .005129864      .012543609      .030671794
    950.0     .004976302      .007167101      .016719469      .039003307
   1100.0     .011717794      .016057490      .033372697      .069359339
   1200.0     .018250125      .024360994      .047635694      .093147242
   1300.0     .026409167      .034477476      .064028021      .118906254
   1400.0     .036097370      .046236641      .082152053      .145965616
   1500.0     .047164946      .059424108      .101613796      .173757147
   1600.0     .059434154      .073808768      .122049523      .201820004
   1700.0     .072717547      .089161518      .143138634      .229792728
   1800.0     .086830513      .105266894      .164607699      .257399962
   1900.0     .101599176      .121929448      .186229330      .284437961
   2000.0     .116864842      .138976501      .207818342      .310760904
   2100.0     .132486011      .156258565      .229226731      .336268890
   2200.0     .148338794      .173648346      .250338399      .360897845
   2300.0     .164316317      .191038982      .271064095      .384611262
   2900.0     .258623212      .291453466      .384663779      .507683868
   3400.0     .330641867      .366122957      .463891770      .587768591
   3900.0     .394690811      .431370662      .530227372      .651738959
   4400.0     .450861633      .487810600      .585705960      .703247267
   4900.0     .499901518      .536539626      .632303043     -.743816110
   5400.0     .542725103      .578699434      .671695599     -.764481386
   5900.0     .580218385      .615322084      .705240506     -.782079812
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TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 3 of 16)

BASE LINE 500.00000

ET= 260.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000000	.000000000	.000000000	.000000000
100.0	.000000000	.000000000	.000000000	.000000000
150.0	.000000000	.000000000	.000000000	.000000000
200.0	.000000000	.000000000	.000000000	.000000027
250.0	.000000001	.000000003	.000000085	.000002123
300.0	.000000051	.000000161	.000002353	.000034394
350.0	.000000868	.000002335	.000023274	.000231954
400.0	.000006934	.000016492	.000123309	.000921949
450.0	.000033720	.000072840	.000435512	.002603958
500.0	.000116578	.000233155	.001165777	.005828885
550.0	.000315831	.000593088	.002561806	.011065564
600.0	.000714740	.001273523	.004869470	.018619014
650.0	.001411293	.002405352	.008295601	.028609950
700.0	.002507229	.004113537	.012986129	.040996237
750.0	.004097623	.006504571	.019019482	.055613303
800.0	.006263033	.009658917	.026410990	.072217247
850.0	.009064854	.013628161	.035123363	.090522162
900.0	.012543609	.018435775	.045079394	.110228714
950.0	.016719469	.024080157	.056174378	.131044024
1100.0	.033372697	.045732308	.095046639	.197537886
1200.0	.047635694	.063586023	.124336651	.243128946
1300.0	.064028021	.083589331	.155233506	.288283697
1400.0	.082152053	.105227471	.186965415	.332195253
1500.0	.101613796	.128025360	.218920287	.374348425
1600.0	.122049523	.151568153	.250631749	-.403983233
1700.0	.143138634	.175507266	.281756870	-.426106774
1800.0	.164607699	.199558204	.312052683	-.446787225
1900.0	.186229330	.223494326	.341354770	-.466140135
2000.0	.207818342	.247139050	.369559078	-.484273464
2100.0	.229226731	.270357903	.396607113	-.501286899
2200.0	.250338399	.293051115	.422474205	-.517271788
2300.0	.271064095	.315147088	.447160363	-.532311443
2900.0	.384663779	.433493926	.572130482	-.606486521
3400.0	.463891770	.513671872	.650841881	-.652768545
3900.0	.530227372	.579503059	-.689458352	-.689458352
4400.0	.585705960	.633705676	-.719216093	-.719216093
4900.0	.632303043	.678644945	-.743816110	-.743816110
5400.0	.671695599	.716218691	-.764481386	-.764481386
5900.0	.705240506	.747908149	-.782079812	-.782079812

TABLE C-1 ATMOSPHERIC TRANSMITTANCE (page 4 of 16)

BASE LINE 500.00000

ET= 2600.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000000	.000000000	.000000000	.000000000
100.0	.000000000	.000000000	.000000000	.000000000
150.0	.000000000	.000000000	.000000000	.000000025
200.0	.000000000	.000000003	.000000150	.000008400
250.0	.000000085	.000000340	.000008494	.000212349
300.0	.000002353	.000007469	.000109193	.001596418
350.0	.000023274	.000062649	.000624374	.006222626
400.0	.000123309	.000293280	.002192776	.016394828
450.0	.000435512	.000940759	.005624860	.033631408
500.0	.001165777	.002331554	.011657771	-.055000000
550.0	.002561806	.004810718	.020779599	-.071593760
600.0	.004869470	.008676409	.033175311	-.089187141
650.0	.008295601	.014138697	.048761677	-.107410867
700.0	.012986129	.021305961	.067261325	-.125967661
750.0	.019019482	.030191546	.088280616	-.144624474
800.0	.026410990	.040731314	.111374220	-.163202453
850.0	.035123363	.052804698	.136091621	-.181566983
900.0	.045079394	.066254740	.162006942	-.199618825
950.0	.056174378	.080904953	.188735703	-.217286625
1100.0	.095046639	.130247255	-.267570103	-.267570103
1200.0	.124336651	.165969517	-.298642162	-.298642162
1300.0	.155233506	.202659158	-.327735972	-.327735972
1400.0	.186965415	.239481512	-.354919231	-.354919231
1500.0	.218920287	.275822278	-.380295246	-.380295246
1600.0	.250631749	.311248996	-.403983233	-.403983233
1700.0	.281756870	.345471916	-.426106774	-.426106774
1800.0	.312052683	.378309602	-.446787225	-.446787225
1900.0	.341354770	.409660788	-.466140135	-.466140135
2000.0	.369559078	.439482285	-.484273464	-.484273464
2100.0	.396607113	.467772092	-.501286899	-.501286899
2200.0	.422474205	.494556718	-.517271788	-.517271788
2300.0	.447160363	.519881787	-.532311443	-.532311443
2900.0	.572130482	-.606486521	-.606486521	-.606486521
3400.0	.650841881	-.652768545	-.652768545	-.652768545
3900.0	-.689458352	-.689458352	-.689458352	-.689458352
4400.0	-.719216093	-.719216093	-.719216093	-.719216093
4900.0	-.743816110	-.743816110	-.743816110	-.743816110
5400.0	-.764481386	-.764481386	-.764481386	-.764481386
5900.0	-.782079812	-.782079812	-.782079812	-.782079812

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 5 of 16)

BASE LINE 250.00000

ET= 2.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000000	.000000000	.000000000	.000000000
100.0	.000000000	.000000000	.000000000	.000000000
150.0	.000000000	.000000000	.000000000	.000000001
200.0	.000000003	.000000007	.000000050	.000000371
250.0	.000000224	.000000448	.000002242	.000011209
300.0	.000003898	.000006945	.000026555	.000101536
350.0	.000028787	.000047229	.000149100	.000470697
400.0	.000125685	.000193832	.000530008	.001449235
450.0	.000388626	.000571177	.001396649	.003415104
500.0	.000946970	.001339217	.002994581	.006696087
550.0	.001944663	.002664871	.005538470	.011510745
600.0	.003517746	.004695627	.009181869	.017954305
650.0	.005777679	.007542828	.014007763	.026013777
700.0	.008802727	.011275296	.020033650	.035595265
750.0	.012636251	.015920678	.027223976	.046552345
800.0	.017289604	.021471229	.035504634	.058710147
850.0	.022747431	.027891418	.044776485	.071883533
900.0	.028973754	.035125637	.054926579	.085889660
950.0	.035917852	.043105112	.065836730	.100555940
1100.0	.060430193	.070740788	.101982748	.147022407
1200.0	.079170135	.091469429	.127907119	.178860100
1300.0	.099233309	.113382977	.154513050	.210563201
1400.0	.120176438	.136011203	.181297057	.241661144
1500.0	.141629084	.158973271	.207883065	.271840470
1600.0	.163291807	.181970224	.233999211	.300904344
1700.0	.184928740	.204773394	.259455711	.328740296
1800.0	.206358246	.227212149	.284125830	.355295645
1900.0	.227443537	.249162574	.307930386	.380559252
2000.0	.248084150	.270537684	.330825531	.404548196
2100.0	.268208605	.291279293	.352793298	.427298179
2200.0	.287768266	.311351422	.373834401	.448856659
2300.0	.306732325	.330735032	.393962785	.469278005
2900.0	.407665680	.432767873	.497177021	.571172228
3400.0	.476180189	.501078630	.564028091	.634885762
3900.0	.532993463	.557209712	.617766632	.684904810
4400.0	.580402673	.603716966	.661527017	.724872778
4900.0	.620309430	.642638968	.697635853	.757339357
5400.0	.654211996	.675546234	.727804606	.784105540
5900.0	.683273777	.703639581	.753299423	.806464041

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 6 of 16)

BASE LINE 250.00000

ET= 26.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000000	.000000000	.000000000	.000000000
100.0	.000000000	.000000000	.000000000	.000000000
150.0	.000000000	.000000000	.000000005	.000000074
200.0	.000000069	.000000164	.000001226	.000009165
250.0	.000002914	.000005829	.000029144	.000145722
300.0	.000033044	.000058878	.000225129	.000860809
350.0	.000179831	.000295044	.000931432	.002940461
400.0	.000624449	.000963032	.002633281	.007200347
450.0	.001615806	.002374806	.005806905	.014199119
500.0	.003414348	.004828617	.010797116	.024143085
550.0	.006239966	.008550944	.017771647	.036935273
600.0	.010242536	.013672145	.026734630	.052277122
650.0	.015495056	.020228977	.037567176	.069765894
700.0	.022001594	.028181548	.050072237	.088967040
750.0	.029712054	.037434842	.064012680	.109460143
800.0	.038538281	.047859065	.079139324	.130864082
850.0	.048368515	.059306321	.095209525	.152848018
900.0	.059079047	.071623068	.111998255	.175133647
950.0	.070542906	.084658733	.129303786	.197492550
1100.0	.108248759	.126718153	.182681956	.263361613
1200.0	.135093022	.156080087	.218256029	.305200331
1300.0	.162508974	.185681114	.253037589	.344827862
1400.0	.189993079	.215027071	.286621794	.382054468
1500.0	.217174920	.243770606	.318769189	.416841873
1600.0	.243791210	.271677692	.349355868	.449243814
1700.0	.269661912	.298599260	.378336667	.479367007
1800.0	.294670176	.324448600	.405718744	.507345998
1900.0	.318746257	.349183974	.431542965	.533327255
2000.0	.341855001	.372795522	.455870970	.557459329
2100.0	.363986278	.395295541	.478776285	.579886963
2200.0	.385147756	.416711346	.500338284	.600747739
2300.0	.405359491	.437080063	.520638162	.620170349
2900.0	.508550107	.539864303	.620212688	.712519381
3400.0	.575014667	.605080951	.681096007	.766660675
3900.0	.628244229	.656788141	.728167132	.807303511
4400.0	.671462309	.698434392	.765314288	.838598394
4900.0	.707037141	.732488653	.795174851	.862447744
5400.0	.736698787	.760722968	.819570374	.874346262
5900.0	.761720674	.784424683	.839785988	.884352764

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 7 of 16)

BASE LINE 250.00000

ET= 260.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000000	.000000000	.000000000	.000000000
100.0	.000000000	.000000000	.000000000	.000000001
150.0	.000000005	.000000016	.000000233	.000003412
200.0	.000001226	.000002915	.000021798	.000162979
250.0	.000029144	.000058289	.000291444	.001457221
300.0	.000225129	.000401134	.001533787	.005864622
350.0	.000931432	.001528173	.004824328	.015230043
400.0	.002633281	.004061074	.011104453	.030363612
450.0	.005806905	.008534609	.020868936	.051028989
500.0	.010797116	.015269428	.034143478	.076347138
550.0	.017771647	.024353394	.050614288	.105192982
600.0	.026734630	.035686449	.069781586	.136451508
650.0	.037567176	.049044387	.091080191	.169144760
700.0	.050072237	.064136862	.113956697	.202475275
750.0	.064012680	.080650923	.137911139	.235824730
800.0	.079139324	.098279788	.162514583	.268732668
850.0	.095209525	.116739716	.187412281	.300869012
900.0	.111998255	.135778404	.212319086	.332007099
950.0	.129303786	.155177825	.237011346	.362000034
1100.0	.182681956	.213851136	.308296349	.444452343
1200.0	.218256029	.252162692	.352614026	.493081075
1300.0	.253037589	.289118195	.393996835	.536920569
1400.0	.286621794	.324387841	.432394976	.576363820
1500.0	.318769189	.357806317	.467889182	.611840195
1600.0	.349355868	.389317548	.500631351	-.635596753
1700.0	.378336667	.418935874	.530807753	-.652768545
1800.0	.405718744	.446719380	.558616759	-.668421443
1900.0	.431542965	.472751865	.584255740	-.682744560
2000.0	.455870970	.497130818	.607913709	-.695897596
2100.0	.478776285	.519959521	.629767507	-.708016171
2200.0	.500338284	.541341958	.649980157	-.719216093
2300.0	.520638162	.561379629	.668700503	-.729596767
2900.0	.620212688	.658402556	.756393074	-.778772445
3400.0	.681096007	.716709057	.806747718	-.807940929
3900.0	.728167132	.761250983	-.830336289	-.830336289
4400.0	.765314288	.796056327	-.848066090	-.848066090
4900.0	.795174851	.823799093	-.862447744	-.862447744
5400.0	.819570374	.846297046	-.874346262	-.874346262
5900.0	.839785988	.864816829	-.884352764	-.884352764

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 8 of 16)

BASE LINE 250.00000

ET= 2600.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000000	.000000000	.000000000	.000000000
100.0	.000000000	.000000000	.000000005	.000000262
150.0	.000000233	.000000741	.000010833	.000158385
200.0	.000021798	.000051845	.000387632	.002898224
250.0	.000291444	.000582889	.002914443	.014572214
300.0	.001533787	.002732898	.010449568	.039955204
350.0	.004824328	.007915134	.024987486	.078883625
400.0	.011104453	.017125408	.046827091	.128042290
450.0	.020868936	.030671794	.074999066	.183388679
500.0	.034143478	.048286170	.107971158	-.234520788
550.0	.050614288	.069359339	.144151307	-.267570103
600.0	.069781586	.093147242	.182140911	-.298642162
650.0	.091080191	.118906254	.220820463	-.327735972
700.0	.113956697	.145965616	.259347884	-.354919231
750.0	.137911139	.173757147	.297120542	-.380295246
800.0	.162514583	.201820004	.333727763	-.403983233
850.0	.187412281	.229792728	.368905979	-.426106774
900.0	.212319086	.257399962	.402500860	-.446787225
950.0	.237011346	.284437961	.434437225	-.466140135
1100.0	.308296349	.360897845	-.517271788	-.517271788
1200.0	.352614026	.407393566	-.546481621	-.546481621
1300.0	.393996835	.450176807	-.572482289	-.572482289
1400.0	.432394976	.489368482	-.595750981	-.595750981
1500.0	.467889182	.525187850	-.616680830	-.616680830
1600.0	.500631351	.557896940	-.635596753	-.635596753
1700.0	.530807753	.587768591	-.652768545	-.652768545
1800.0	.558616759	.615068779	-.668421443	-.668421443
1900.0	.584255740	.640047489	-.682744560	-.682744560
2000.0	.607913709	.662934601	-.695897596	-.695897596
2100.0	.629767507	.683938661	-.708016171	-.708016171
2200.0	.649980157	.703247267	-.719216093	-.719216093
2300.0	.668700503	.721028285	-.729596767	-.729596767
2900.0	.756393074	-.778772445	-.778772445	-.778772445
3400.0	.806747718	-.807940929	-.807940929	-.807940929
3900.0	-.830336289	-.830336289	-.830336289	-.830336289
4400.0	-.848066090	-.848066090	-.848066090	-.848066090
4900.0	-.862447744	-.862447744	-.862447744	-.862447744
5400.0	-.874346262	-.874346262	-.874346262	-.874346262
5900.0	-.884352764	-.884352764	-.884352764	-.884352764

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 9 of 16)

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BASE LINE         75.00000
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                    ET=         2.00000
   RVR     I=  20000.0     I=  10000.0      I=    2000.0      I=     400.0


    50.0     .000000000      .000000000      .000000000      .000000000
   100.0     .000002606      .000004384      .000014657      .000049009
   150.0     .000284091      .000401765      .000898374      .002008826
   200.0     .002715170      .003521140      .006438683      .011773641
   250.0     .010120073      .012459272      .020192201      .032724623
   300.0     .023836565      .028346612      .042388072      .063384952
   350.0     .043426765      .050380666      .071128425      .100420524
   400.0     .067574801      .076953415      .104060229      .140715407
   450.0     .094811175      .106421946      .139163774      .181978968
   500.0     .123851373      .137421702      .174944714      .222713388
   550.0     .153692721      .168928469      .210386048      .262017940
   600.0     .183602813      .200220288      .244838287      .299399163
   650.0     .213071824      .230812993      .277914137      .334627034
   700.0     .241760401      .260398442      .309405497      .367635692
   750.0     .269454517      .288794201      .339223139      .398457925
   800.0     .296029855      .315905418      .367354625      .427182989
   850.0     .321425040      .341697008      .393835627      .453929936
   900.0     .345622041      .366173798      .418730663      .478831006
   950.0     .368632064      .389366545      .442120321      .502021502
  1100.0     .430899703      .451752919      .504147959      .562619861
  1200.0     .467270556      .487958391      .539595620      .596697256
  1300.0     .500031359      .520432437      .571070268      .626635135
  1400.0     .529597343      .549632500      .599124703      .653073480
  1500.0     .556346978      .575966512      .624231577      .676541176
  1600.0     .580616426      .599791213      .646791521      .697474826
  1700.0     .602700183      .621415467      .667143057      .716235565
  1800.0     .622854417      .641105444      .685572226      .733123204
  1900.0     .641301240      .659090183      .702321177      .748387776
  2000.0     .658233082      .675566850      .717595498      .762238851
  2100.0     .673816765      .690705451      .731570354      .774852989
  2200.0     .688197150      .704652920      .744395568      .786379714
  2300.0     .701500305      .717536602      .756199802      .796946302
  2900.0     .763996282      .777815340      .810873886      .845337480
  3400.0     .800444817      .812777672      .842151488      .872586875
  3900.0     .827973744      .839084316      .865460665      .892666146
  4400.0     .849412839      .859508180      .883413996      .907984714
  4900.0     .866527829      .875770107      .897611974      .919998582
  5400.0     .880472003      .888989278      .909084891      .929634766
  5900.0     .892027875      .899922434      .918523539      .937509122
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TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 10 of 16)

BASE LINE 75.00000

ET= 26.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000000	.000000000	.000000001	.000000014
100.0	.000017845	.000030011	.000100348	.000335532
150.0	.001024304	.001448585	.003239135	.007242925
200.0	.007104374	.009213233	.016847126	.030806302
250.0	.021845735	.026895254	.043587971	.070641133
300.0	.045261559	.053825367	.080487698	.120357180
350.0	.075241878	.087290314	.123238199	.173990136
400.0	.109307297	.124477907	.168325206	.227617700
450.0	.145384048	.163188076	.213394599	.279047685
500.0	.181966871	.201904885	.257035037	.327218484
550.0	.218049285	.239664777	.298482108	.371734094
600.0	.253001008	.275899555	.337382266	.412566064
650.0	.286456017	.310307433	.373630709	.449876128
700.0	.318226426	.342759464	.407266885	.483914619
750.0	.348240922	.373235378	.438409346	.514963922
800.0	.376502359	.401780878	.467215994	.543308049
850.0	.403059188	.428479744	.493860305	.569217107
900.0	.427986474	.453435874	.518517451	.592940175
950.0	.451373444	.476761887	.541356521	.614702833
1100.0	.513247542	.538085948	.600494033	.670140310
1200.0	.548516726	.572801636	.633417233	.700447356
1300.0	.579779966	.603434755	.662148672	.726575425
1400.0	.607604994	.630591252	.687373465	.749268690
1500.0	.632474327	.654778485	.709647866	.769115213
1600.0	.654795088	.676419616	.729424612	.786583137
1700.0	.674910031	.695867604	.747073842	.802048151
1800.0	.693107909	.713417521	.762899836	.815814221
1900.0	.709632550	.729316923	.777154225	.828129267
2000.0	.724690522	.743774365	.790046369	.839197065
2100.0	.738457496	.756966351	.801751515	.849186348
2200.0	.751083483	.769042954	.812417221	.858237810
2300.0	.762697115	.780132371	.822168435	.866469539
2900.0	.816394603	.831161434	.866487285	.903314548
3400.0	.847039526	.860090289	.891173985	.923381047
3900.0	.869838352	.881510705	.909220714	.937801779
4400.0	.887373575	.897920083	.922894263	.948563060
4900.0	.901223833	.910836174	.933552596	-.956576786
5400.0	.912403592	.921229759	.942054168	-.960516959
5900.0	.921592057	.929748262	.948965857	-.963801641

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 11 of 16)

BASE LINE 75.00000

ET= 260.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000001	.000000004	.000000040	.000000445
100.0	.000100348	.000168764	.000564296	.001886836
150.0	.003239135	.004580828	.010243043	.022904141
200.0	.016847126	.021848019	.039950831	.073053254
250.0	.043587971	.053663087	.086969437	.140947591
300.0	.080487698	.095716543	.143129615	.214028696
350.0	.123238199	.142972256	.201851070	.284977349
400.0	.168325206	.191686831	.259208450	.350514534
450.0	.213394599	.239527338	.313220436	.409585987
500.0	.257035037	.285198231	.363071640	.462208394
550.0	.298482108	.328071004	.408584549	.508857325
600.0	.337382266	.367917970	.449906483	.550165688
650.0	.373630709	.404740621	.487334524	.586783056
700.0	.407266885	.438664321	.521221061	.619315000
750.0	.438409346	.469875502	.551924666	.648301168
800.0	.467215994	.498585063	.579785969	.674211474
850.0	.493860305	.525007600	.605117084	.697450256
900.0	.518517451	.549350103	.628198233	.718363422
950.0	.541356521	.571806251	.649278080	.737246269
1100.0	.600494033	.629554697	.702571477	.784056862
1200.0	.633417233	.661461010	.731458810	.808863988
1300.0	.662148672	.689164070	.756219409	.829799201
1400.0	.687373465	.713377438	.777614216	.847635258
1500.0	.709647866	.734673544	.796238002	.862961462
1600.0	.729424612	.753513771	.812559950	-.872879916
1700.0	.747073842	.770272273	.826953667	-.879888751
1800.0	.762899836	.785254508	.839719403	-.886166059
1900.0	.777154225	.798711569	.851100599	-.891820548
2000.0	.790046369	.810851279	.861296299	-.896940431
2100.0	.801751515	.821846785	.870470535	-.901598028
2200.0	.812417221	.831843269	.878759493	-.905853192
2300.0	.822168435	.840963206	.886277033	-.909755878
2900.0	.866487285	.882160185	.919653574	-.927733359
3400.0	.891173985	.904904750	.937608042	-.938023854
3900.0	.909220714	.921421539	-.945749686	-.945749686
4400.0	.922894263	.933862937	-.951763202	-.951763202
4900.0	.933552596	.943509751	-.956576786	-.956576786
5400.0	.942054168	.951167160	-.960516959	-.960516959
5900.0	.948965857	.957364324	-.963801641	-.963801641

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 12 of 16)

BASE LINE 75.00000

ET= 1000.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000009	.000000027	.000000300	.000003357
100.0	.000275598	.000463499	.001549803	.005182080
150.0	.006352466	.008983743	.020088261	.044918717
200.0	.027919704	.036207376	.066208051	.121066659
250.0	.065294207	.080386598	.130279071	.211137636
300.0	.112716155	.134042854	.200440818	.299728933
350.0	.164478144	.190815928	.269397717	.380341046
400.0	.216691388	.246765690	.333688816	.451230583
450.0	.267108596	.299819262	.392061801	.512683726
500.0	.314591023	.349060595	.444371631	.565707356
550.0	.358669679	.394225043	.490973781	.611466111
600.0	.399255201	.435390884	.532415368	.651061228
650.0	.436461197	.472802614	.569285673	.685457669
700.0	.470500973	.506773316	.602148187	.715472632
750.0	.501628807	.537632443	.631513252	.741787429
800.0	.530107502	.565699132	.657830416	-.761919348
850.0	.556191207	.591269652	.681489883	-.774204215
900.0	.580117008	.614612560	.702827800	-.785290284
950.0	.602101469	.635967926	.722132773	-.795343890
1100.0	.658259108	.690115290	.770155986	-.820570005
1200.0	.689055242	.719562323	.795708579	-.834204769
1300.0	.715660504	.744859163	.817333609	-.845918683
1400.0	.738811210	.766761121	.835804885	-.856090011
1500.0	.759091684	.785860995	.851714878	-.865004037
1600.0	.776968724	.802628022	.865522848	-.872879916
1700.0	.792818051	.817436949	.877589011	-.879888751
1800.0	.806944437	.830589714	-.886166059	-.886166059
1900.0	.819597018	.842331676	-.891820548	-.891820548
2000.0	.830980975	.852863848	-.896940431	-.896940431
2100.0	.841266506	.862352188	-.901598028	-.901598028
2200.0	.850595755	.870934706	-.905853192	-.905853192
2300.0	.859088203	.878726960	-.909755878	-.909755878
2900.0	.897206050	.913434587	-.927733359	-.927733359
3400.0	.918052462	.932197357	-.938023854	-.938023854
3900.0	.933082048	.945603068	-.945749686	-.945749686
4400.0	.944330445	-.951763202	-.951763202	-.951763202
4900.0	.953000833	-.956576786	-.956576786	-.956576786
5400.0	.959845306	-.960516959	-.960516959	-.960516959
5900.0	-.963801641	-.963801641	-.963801641	-.963801641

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 13 of 16)

BASE LINE 60.00000

ET= 26.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000005	.000000011	.000000076	.000000523
100.0	.000158930	.000240893	.000632711	.001661833
150.0	.004058291	.005354947	.010193967	.019405785
200.0	.019108238	.023525001	.038125948	.061789069
250.0	.046934622	.055429444	.081563025	.120017929
300.0	.084058881	.096558298	.133224348	.183813584
350.0	.126231488	.142158504	.187325230	.246842367
400.0	.170184234	.188831230	.240391620	.306030579
450.0	.213802808	.234504260	.290634213	.360199196
500.0	.255854973	.278046518	.337282542	.409138419
550.0	.295694831	.318921185	.380132185	.453091500
600.0	.333041076	.356944587	.419273874	.492487034
650.0	.367829332	.392133317	.454939924	.527806044
700.0	.400118833	.424611316	.487419925	.559519199
750.0	.430035039	.454554794	.517015833	.588059734
800.0	.457735042	.482160258	.544019117	.613814172
850.0	.483387105	.507626443	.568700089	.637121638
900.0	.507158881	.531144516	.591303843	.658277031
950.0	.529210928	.552893169	.612049712	.677535682
1100.0	.586491203	.609089791	.664977509	.725993268
1200.0	.618517369	.640329337	.693987902	.752142969
1300.0	.646562576	.667581443	.719058807	.774505603
1400.0	.671269736	.691509822	.740890815	.793798123
1500.0	.693161321	.712648739	.760036275	.810574844
1600.0	.712663194	.731430313	.776934363	.825269330
1700.0	.730124138	.748206186	.791937347	.838224506
1800.0	.745831435	.763264418	.805330259	.849714477
1900.0	.760023153	.776842599	.817345677	.859960506
2000.0	.772897789	.789138015	.828174902	.869142857
2100.0	.784621858	.800315558	.837976484	.877409642
2200.0	.795335869	.810513920	.846882769	.884883536
2300.0	.805159058	.819850450	.855004970	.891666888
2900.0	.850198041	.862478558	.891681498	.921873230
3400.0	.875634655	.886411201	.911947842	.938220169
3900.0	.894439236	.904028397	.926692093	.949923960
4400.0	.908835314	.917466357	.937824463	.958634305
4900.0	.920165900	.928009060	.946479109	-.965107898
5400.0	.929286417	.936471073	.953368285	-.968286841
5900.0	.936765695	.943392241	.958959950	-.970934938

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 14 of 16)

BASE LINE 60.00000

ET= 260.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000076	.000000174	.000001202	.000008293
100.0	.000632711	.000959010	.002518867	.006615875
150.0	.010193967	.013451020	.025606087	.048745128
200.0	.038125948	.046938548	.076071267	.123285401
250.0	.081563025	.096325334	.141740293	.208567256
300.0	.133224348	.153034589	.211146362	.291324899
350.0	.187325230	.210960631	.277987229	.366309578
400.0	.240391620	.266731202	.339562188	.432279683
450.0	.290634213	.318774865	.395075475	.489639078
500.0	.337282542	.366535697	.444624983	.539349478
550.0	.380132185	.409990957	.488681109	.582474375
600.0	.419273874	.449366611	.527834534	.620004442
650.0	.454939924	.484999661	.562680343	.652802865
700.0	.487419925	.517256373	.593769061	.681599525
750.0	.517015833	.546495062	.621589748	.707003303
800.0	.544019117	.573048540	.646567932	.729519511
850.0	.568700089	.597217427	.669069960	.749567228
900.0	.591303843	.619269040	.689409666	.767494671
950.0	.612049712	.639438997	.707855470	.783592132
1100.0	.664977509	.690600319	.753967128	.823148229
1200.0	.693987902	.718461333	.778667234	.843918292
1300.0	.719058807	.742434427	.799683722	.861347525
1400.0	.740890815	.763230111	.817732678	.876127295
1500.0	.760036275	.781403804	.833363204	.888777642
1600.0	.776934363	.797393985	.847001794	-.896940431
1700.0	.791937347	.811550243	.858983738	-.902697444
1800.0	.805330259	.824153961	.869575611	-.907845802
1900.0	.817345677	.835433681	.878991585	-.912477112
2000.0	.828174902	.845576617	.887405396	-.916665488
2100.0	.837976484	.854737363	.894959248	-.920471535
2200.0	.846882769	.863044532	.901770499	-.923945288
2300.0	.855004970	.870605880	.907936752	-.927128425
2900.0	.891681498	.904561214	.935189044	-.941756309
3400.0	.911947842	.923171299	.949766963	-.950103912
3900.0	.926692093	.936627032	-.956359033	-.956359033
4400.0	.937824463	.946730812	-.961220728	-.961220728
4900.0	.946479109	.954546554	-.965107898	-.965107898
5400.0	.953368285	.960739127	-.968286841	-.968286841
5900.0	.958959950	.965743496	-.970934938	-.970934938

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 15 of 16)

BASE LINE 60.00000

ET= 2600.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000001202	.000002762	.000019052	.000131432
100.0	.002518867	.003817889	.010027792	.026338274
150.0	.025606087	.033787434	.064319582	.122442225
200.0	.076071267	.093654715	.151782132	.245986714
250.0	.141740293	.167394246	.246316398	.362448350
300.0	.211146362	.242543479	.334644432	.461718849
350.0	.277987229	.313061735	.412527986	.543596743
400.0	.339562188	.376767838	.479644339	.610611282
450.0	.395075475	.433328650	.537048372	.665594010
500.0	.444624983	.483189470	.586129880	-.706063112
550.0	.488681109	.527066225	.628226801	-.728760828
600.0	.527834534	.565719046	.664504308	-.748231985
650.0	.562680343	.599858929	.695936213	-.765113362
700.0	.593769061	.630115461	.723322293	-.779885934
750.0	.621589748	.657031577	.747315247	-.792919348
800.0	.646567932	.681069467	.768447428	-.804502136
850.0	.669069960	.702620323	.787154108	-.814862675
900.0	.689409666	.722014692	.803792658	-.824184000
950.0	.707855470	.739532072	.818657957	-.832614480
1100.0	.753967128	.783018872	-.853674896	-.853674896
1200.0	.778667234	.806126874	-.865004037	-.865004037
1300.0	.799683722	.825680348	-.874707587	-.874707587
1400.0	.817732678	.842388906	-.883111507	-.883111507
1500.0	.833363204	.856792233	-.890460189	-.890460189
1600.0	.847001794	.869306556	-.896940431	-.896940431
1700.0	.858983738	.880257086	-.902697444	-.902697444
1800.0	.869575611	.889900977	-.907845802	-.907845802
1900.0	.878991585	.898443824	-.912477112	-.912477112
2000.0	.887405396	.906051669	-.916665488	-.916665488
2100.0	.894959248	.912859873	-.920471535	-.920471535
2200.0	.901770499	.918979731	-.923945288	-.923945288
2300.0	.907936752	.924503485	-.927128425	-.927128425
2900.0	.935189044	-.941756309	-.941756309	-.941756309
3400.0	.949766963	-.950103912	-.950103912	-.950103912
3900.0	-.956359033	-.956359033	-.956359033	-.956359033
4400.0	-.961220728	-.961220728	-.961220728	-.961220728
4900.0	-.965107898	-.965107898	-.965107898	-.965107898
5400.0	-.968286841	-.968286841	-.968286841	-.968286841
5900.0	-.970934938	-.970934938	-.970934938	-.970934938

TABLE C-1. ATMOSPHERIC TRANSMITTANCE (page 16 of 16)

BASE LINE 60.00000

ET= 2.00000

RVR	I= 20000.0	I= 10000.0	I= 2000.0	I= 400.0
50.0	.000000000	.000000001	.000000003	.000000024
100.0	.000034107	.000051696	.000135781	.000356633
150.0	.001454675	.001919455	.003653978	.006955909
200.0	.008851923	.010897996	.017661909	.028623889
250.0	.025359864	.029949813	.044070393	.064848468
300.0	.050326292	.057809729	.079761798	.110049718
350.0	.081321613	.091582212	.120679793	.159022283
400.0	.115831804	.128523434	.163616772	.208292351
450.0	.151875466	.166580805	.206452886	.255868580
500.0	.188070492	.204382760	.247925193	.300744061
550.0	.223523217	.241080607	.287351553	.342503349
600.0	.257693501	.276189056	.324416897	.381066232
650.0	.290282476	.309462623	.359028158	.416532429
700.0	.321150154	.340808726	.391221235	.449090776
750.0	.350258251	.370229290	.421103038	.478967422
800.0	.377631670	.397782488	.448816081	.506397042
850.0	.403333008	.423558051	.474517245	.531607451
900.0	.427445889	.447661568	.498365318	.554811957
950.0	.450064218	.470204636	.520513959	.576206104
1100.0	.509918720	.529566829	.578157828	.631207350
1200.0	.544069941	.563256526	.610456514	.661611785
1300.0	.574377995	.593050239	.638780485	.688037000
1400.0	.601390604	.619523698	.663764133	.711163794
1500.0	.625570970	.643158164	.685924929	.731535467
1600.0	.647308716	.664354803	.705685923	.749588353
1700.0	.666931237	.683448267	.723394457	.765675421
1800.0	.684714049	.700718481	.739337223	.780084363
1900.0	.700889678	.716400490	.753752232	.793051422
2000.0	.715655090	.730692525	.766838245	.804772012
2100.0	.729177820	.743762550	.778762227	.815408905
2200.0	.741600981	.755753566	.789665243	.825098583
2300.0	.753047361	.766787894	.799667135	.833956212
2900.0	.806256068	.817901874	.845595477	.874226767
3400.0	.836883716	.847183349	.871589874	.896699528
3900.0	.859831303	.869049437	.890836222	.913169194
4400.0	.877596852	.885931230	.905589588	.925684154
4900.0	.891714876	.899315531	.917214496	.935469702
5400.0	.903176109	.910158897	.926581344	.943300111
5900.0	.912646811	.919102744	.934269632	.949686800

APPENDIX D

SIMULATOR SOFTWARE

A complete listing of the simulator software is included in this appendix. The software was specifically written for a configuration consisting of a PDP-11/10 minicomputer with 8k memory, a teletype (including a slow paper-tape reader/punch), and the simulator-interface. Also included in the appendix is a listing of PDP-11 instructions, a brief software description, typical teletype I/O, estimates of the processor time requirements for an RVR update, and comments on the program size.

D.1 SOFTWARE DESCRIPTION

```
RVR VISIBILITY PROGRAMME
------------------------

CALCULATES RVR FOR A GIVEN BASE LENGTH,TRANSMISSIVITY OF A TRANS-
MISSOMETER, RUNWAY LIGHT INTENSITY AND PILOT'S VISUAL LUMINANCE
THRESHOLD. USES ALLARD'S AND KOSCHMIEDER'S LAWS IN CALCULATING
RVR.VARIOUS PROVISIONS OF THE PROGRAMME ARE AS FOLLOWS:

PARAMETER LIST
--------------

LIST IS INPUT FROM TTY KB AND CAN BE INPUT ANYTIME DURING
THE PROGRAMME FLOW WITH THE HELP OF EXECUTIVE PROGRAMME.LIST
IS AS FOLLOWS:
        SCALE:  SCALE IN INTEGER ARITHMETIC =2**SCALE
        EXITSC: EXIT CRITERIAN IN ITERATIVE ROUTINES IS--
                EXIT IF CHANGE IN RVR<RVR/2**EXITSC
        BASE:   BASE LENGTH OF TRANSMISSOMETER,IN FT.
        PRATE:  MAX. PULSE RATE, IN PULSES/SEC
        TW:     TIME WINDOW,IN SECS,DURING WHICH PULSES ARE COUNTED.
        INMODE: INPUT MODE IN DATA LIST DESCRIBED BELOW.
                INMODE=0:DATA LIST INPUT FROM TTY KB
                INMODE=1:DATA LIST INPUT FROM INTERFACE.


DATA LIST
---------

DATA LIST: INTSTY,ET,NPUL1,NPUL2
IT IS ASSEMBLED FROM TTY OR INTERFACE DEPENDING ON THE
FLAG INMODE.ASSEMBLY IS DESCRIBED BELOW.
```

TTY MODE:

INTSTY: RUNWAY LIGHT INTENSITY .IN CANDLES
ET: PILOT'S VISUAL ILLUMINANCE THRESHOLD.MILE-CANDLES.
NPUL1: PULSE COUNT FOR TR.1.
NPUL2: PULSE COUNT FOR TR.2.

INTERFACE MODE:

INTSTY:ASSEMBLED BY CHECKING POSITION OF RUNWAY LIGHT SETTING SWITCH.

POS.	INTENSITY.CANDLES
1	400
2	2.000
3	10.000
4	20.000

ET: ASSEMBLED BY CHECKING B/G ILLUMINANCE SWITCH SETTING.

POS.	ET.MILE-CANDLES	
1	2	NIGHT.
2	26	INTERMEDIATE
3	260	NORMAL DAY
4	2600	BRIGHT DAY

NPUL1: PUPSE COUNT ACCUMULATED DURING TW SECS. PULSE RATE DEPENDS ON SWITCH SETTING.

POS.	FREQ. /SEC
0	10000
1	100
2	50
3	25
4	12.5
5	6.25
6	3.125
7	1.00
8	0.50
9	0.167

NPUL2: PULSE COUNT FROM PRESET COUNT TRANSMISSOMETER
RSELCT: RUNWAY SELECTOR SWITCH POSITION SETTING FOR STROBING CORRESPONDING RVR ON VISUAL DISPLAY.

NOTE--IN INTERFACE MODE A PROVISIN IS MADE IN SOFTWARE WHEREBY ONE CAN MAKE CHANGES IN VARIOUS SWITCH SETTINGS AT APPROPRIATE RUN TIME.FOR EX., PULSE RATE SWITCH SETTING CAN BE CHANGED IN BETWEEN TIME WINDOWS.WHEN & SYMBOL IS PRINTED ON TTY.PROGRAMME GOES INTO STALL MODE WAITING FOR ANY INPUT FROM TTY KB TO RESUME PROGRAMME FLOW.ALSO A RESET SWITCH IS PROVIDED FOR MAKING CHANGES IN INTENSITY SWITCH SETTING OR B/G ILLUMINANCE SWITCH SETTING. UNLESS RESET SWITCH IS IN POSITION 0, PROGRAMME GOES INTO STALL MODE.

OUTPUT PROVISIONS

(1)RVR FOR THE TRANSMISSOMETER SELECTED BY RUNWAY SELECTOR SWITCH IS SHOWN ON VISUAL LED DISPLAY EITHER EVERY TIME NEW RVR IS CALCULATED FOR THAT RUNWAY OR RUNWAY SELECTOR SWITCH POSITION IS CHANGED.LATTER ACTION DOES NOT INTERFERE WITH THE CALCULATIONS THAT MAY BE UNDER PROGRESS.
(2)RVR AND RELEVANT DATA ARE PRINTED ON TTY ONCE EVERY TIME WINDOW.
(3)A PROVISION IS MADE FOR DIAGNOSTIC PRINTOUT OF INTERMEDIATE RVR ITERATE VALUES DURING ALLARD'S LAW CALCULATIONS. IF FLAG DIAGNOIS OTHER THAN ZERO.FLAG DIAGNO IS ENTERED FROM TTY KB DURING PARAMETER INPUT MODE.

CALCULATION OF RVR

RVR IS CALCULATED IN INTEGER ARITHMETIC USING ALLARD'S AND KOSCHMIEDER'S LAWS.FOR ALLARD'S LAW PROVISION IS MADE FOR THREE DIFFERENT ITERATIVE ALGORITNMS DEPENDING UPON FLAG MODNR.

MODNR=0	NEWTON-RAPHSON METHOD
=1	MOD. NEWTON-RAPHSON METHOD
=2	HALLEY'S METHOD

NORMALLY MODNR=0.IF OTHER METHODS ARE TO BE USED. CORRESPONDING VALUE FOR MODNR HAS TO BE ENTERED FROM SWITCH REGISTER IN APPROPRIATE MEMORY LOCATION.

MONITORING PROVISIONS

MONITORING OF THE PROGRAMME CAN BE DONE DURING RUNTIME DIRECTLY BY ISSUING MONITOR COMMANDS FROM TTY KB.THE MONITOR COMMANDS PROVIDE FOR:

-SETTING THE TIME-OF-DAY AND DATE-OF-DAY FROM TTY KB ANYTIME WITHOUT DISRUPTING THE RUNNING OF THE VISIBILITY PROGRAMME. ONCE SO ENTERED BOTH TIME AND DATE ARE UPDATED INTERNALLY AS LONG AS COMPUTER IS RUNNING. ALSO THE TIME AND THE DATE OF THE DAY CAN BE PRINTED ON TTY ANYTIME WITHOUT DISRUPTING THE FLOE OF VISIBILITY PROGRAMME.

-THERE ARE THREE SEPARATE SOFTWARE CHECK-OUT PROVISIONS FOR ALL THE THREE SOFTWARE MODULES ,VIZ.

TTY I/O AND EXECUTIVE PACKAGE
ARITHMETIC PACKAGE
VISIBILITY PACKAGE

AS EXPLAINED ABOVE ,FOR THE LAST PACKAGE. THERE ARE PROVISIONS FOR:

ENTERING THE APPROPRIATE DATA LIST FROM TTY TO SIMULATE INTERFACE INPUTS.

CHANGING THE BASIC PARAMETER LIST FOR RVR SYSTEM FROM TTY.

THREE DIFFERENT ITERATIVE ALGORITHMS FOR RVR COMPUTATION FROM ALLARD'S LAW.

DIAGNOSTIC PRINTOUT TO CHECK THE RVR ITERATES IN THESE ALGORITHMS.

D.2 TYPICAL TELETYPE I/O

Typical teletype I/O is shown in Table D-1. The entries from the keyboard are echoed on the teletype and are underlined in the printout. The printout shows:

(1) Input data list which selects the scale factor, exit scale factor, diagnostic mode flag, initial RVR guess, transmissometer baselength, maximum pulse rate (for $t_b = 1$), the length of the time window in seconds, and the input mode for the data list.

(2) Data list inputs from the teletype including the runway-light intensity, visual-illuminance threshold, and simulated pulse counts from the transmissometers.

(3) Diagnostic printout of intermediate values of RVR, function f(v), and the increments in RVR during iterative solution of Allard's Law.

(4) Printout of the input data and the appropriate RVR values.

TABLE D-1. TYPICAL TELETYPE INPUT/OUTPUT PRINTOUT

```
SCALE=10
EXITSC=14, DIAGNO=1, VI=1000      , BASE=60
PRATE=1000, TW=10, INMODE=0

INTSTY=10000, ET=26
NPUL1=7632, NPUL2=9280

V           F(V)        DELV
+01525      -01064      +00525
+01734      -00351      +00209
+01787      -00085      +00053
+01798      -00018      +00011
+01801      -00005      +00003
+01801      -00001      +00000

V           F(V)        DELV
+02377      -01789      +01377
+03829      -01025      +01452
+04592      -00414      +00763
+04841      -00124      +00249
+04904      -00031      +00063
+04920      -00008      +00016
+04924      -00002      +00004
+04926      -00001      +00002
+04926      +00000      +00000

ET          I           NPUL1       RVR1        NPUL2       RVR2
+00026      +10000      +07632      +01801      +09280      +04926
```

D.3 PDP-11 — INSTRUCTION SET

A brief repertoire of the PDP-11 instructions is reproduced from the PDP-11 handbook.

INSTRUCTIONS

Mnemonic	Instruction Operation	OP Code	Condition Codes ZNCV	Timing
DOUBLE OPERAND GROUP: OPR scr, dst				
MOV(B)	MOVe (Byte) (src) → (dst)	·1SSDD	✓✓—0	2.3
CMP(B)	CoMPare (Byte) (src) — (dst)	·2SSDD	✓✓✓✓	2.3*
BIT(B)	BIt Test (Byte) (src) ∧ (dst)	·3SSDD	✓✓—0	2.9*
BIC(B)	BIt Clear (Byte) ~ (src) ∧ (dst) → (dst)	·4SSDD	✓✓—0	2.9
BIS(B)	BIt Set (Byte) (src) v	·5SSDD	✓✓—0	2.3
ADD	ADD (src) + (dst) → (dst)	06SSDD	✓✓✓✓	2.3
SUB	SUBtract (dst) — (src) → (dst)	16SSDD	✓✓✓✓	2.3
CONDITIONAL BRANCHES: Bxx loc				
BR	BRanch (unconditionally) loc → (PC)	0004XX	——	2.6
BNE	Branch if Not Equal (Zero) loc → (PC) if Z = 0	0010XX	——	2.6—
BEQ	Branch if Equal (Zero) loc → (PC) if Z = 1	0014XX	——	2.6—
BGE	Branch if Greater or Equal (Zero) loc → (PC) if N ⊻ V = 0)	0020XX	——	2.6—
BLT	Branch if Less Than (Zero) loc → (PC) if N ⊻ V = 1	0024XX	——	2.6—
BGT	Branch if Greater Than (Zero) loc → (PC) if Z v (N ⊻ V = 0)	0030XX	——	2.6—
BLE	Branch if Less Than or Equal (Zero) loc → (PC) if Z v (N ⊻ V) = 1	0034XX	——	2.6—
BPL	Branch if PLus loc → (PC) if N = 0	1000XX	——	2.6—
BMI	Branch if MInus loc → (PC) if N = 1	1004XX	——	2.6—
BHI	Branch if HIgher loc → (PC) if C v Z = 0	1010XX	——	2.6—
BLOS	Branch if LOwer or Same loc → (PC) if C v Z = 1	1014XX	——	2.6—
BVC	Branch if oVerflow Clear loc → (PC) if V = 0	1020XX	——	2.6—
BVS	Branch if oVerflow Set loc → (PC) if V = 1	1024XX	——	2.6—
BCC (or BHIS)	Branch if Carry Clear loc → (PC) if C = 0	1030XX	——	2.6—
BCS (or BLO)	Branch if Carry Set loc → (PC) if C = 1	1034XX	——	2.6—
SUBROUTINE CALL: JSR reg, dst				
JSR	Jump to SubRoutine (dst) → (tmp), (reg) ↓ (PC) → (reg), (tmp) → (PC)	004RDD	——	4.4
SUBROUTINE RETURN: RTS reg				
RTS	ReTurn from Subroutine (reg) → PC, ↑ (reg)	00020R	——	3.5

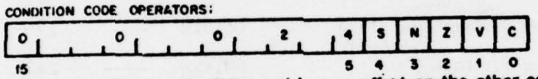
SINGLE OPERAND GROUP: OPR dst

CLR(B)	CLeaR (Byte) 0 → (dst)	·050DD	1000	2.3
COM(B)	COMplement (Byte) ~ (dst) → (dst)	·051DD	✓✓00	2.3
INC(B)	INCrement (Byte) (dst) + 1 → (dst)	·052DD	✓✓—✓	2.3
DEC(B)	DECrement (Byte) (dst) — 1 → (dst)	·053DD	✓✓—✓	2.3
NEG(B)	NEGate (Byte) ~ (dst) + 1 → (dst)	·054DD	✓✓✓✓	2.3
ADC(B)	ADd Carry (Byte) (dst) + (C) → (dst)	·055DD	✓✓✓✓	2.3
SBC(B)	SuBtract Carry (Byte) (dst) — (C) → (dst)	·056DD	✓✓✓✓	2.3
TST(B)	TeST (Byte) 0 — (dst)	·057DD	✓✓00	2.3•
ROR(B)	ROtate Right (Byte) rotate right 1 place with C	·060DD	✓✓✓✓	2.3•
ROL(B)	ROtate Left (Byte) rotate left 1 place with C	·061DD	✓✓✓✓	2.3•
ASR(B)	Arithmetic Shift Right (Byte) shift right with sign extension	·062DD	✓✓✓✓	2.3•
ASL(B)	Arithmetic Shift Left (Byte) shift left with lo-order zero	·063DD	✓✓✓✓	2.3•
JMP	JuMP (dst) → (PC)	0001DD	——	1.2
SWAB	SWAp Bytes bytes of a word are exchanged	0003DD	✓✓00	2.3

CONDITION CODE OPERATORS: OPR 1.5

Condition Code Operators set or clear combinations of condition code bits. Selected bits are set if S = 1 and cleared otherwise. Condition code bits corresponding to bits set as marked in the word below are set or cleared.

CONDITION CODE OPERATORS:



Thus SEC = 000261 sets the C bit and has no effect on the other condition code bits (CLC = 000241 clears the C Bit)

OPERATE GROUP: OPR

HALT	HALT processor stops; (RO) and the HALT address in lights	000000	——	1.8
WAIT	WAIT processor releases bus, waits for interrupt	000001	——	1.8
RTI	ReTurn from Interrupt ↑ (PC), ↑ (PS)	000002	✓✓✓✓	4.8
IOT	Input/Output Trap (PS) ↓, (PC) ↓, (20) → (PC), (22) → (PS)	000004	✓✓✓✓	9.3
RESET	RESET an INIT pulse is issued by the CP	000005	——	20 ms
EMT	EMulator Trap (PS) ↓, (PC) ↓, (30) → (PC), (32) → (PS)	104000—104377	✓✓✓✓	9.3
TRAP	TRAP (PS) ↓, (PC) ↓ (34) → (PC), (36) → (PS)	104400—104777	✓✓✓✓	9.3

NOTATION:

1. for order codes
   - · — word/byte bit, set for byte (+100000)
   - SS—source field,
   - DD—destination field
   - XX—offset (8 bit)
2. for operations

∧	and,
v	or,
~	not,
( )	contents of,
⊻	XOR
↓	"is pushed onto the processor stack"
↑	"the contents of the top of the processor stack is popped and becomes"
→	"becomes"

3. for timing

•	0.4 μs less if not register mode
—	0.9 μs less if conditions for branch not met
•	1.2 μs more if addressing odd byte (0.6 μs additional in addressing odd bytes otherwise)

4. for condition codes

✓	set conditionally
—	not affected
0	cleared
1	set

D.4 RVR UPDATE TIME REQUIREMENTS

Table D-2 gives the estimates of processor time requirements for different elements of computations involved in an RVR update. Estimates are given for two cases when integer and floating-point arithmetic is employed in the calculations. The integer and floating-point multiply and divide capability is assumed to be supplied by software rather than by hardware. Thus, it may be seen that for integer and floating-point arithmetic calculations the processor time required to update RVR for n transmissometers is less than or equal to 0.1 seconds and 0.3 seconds, respectively. The time involved in the data input operations and in the output of RVR to the display is very small compared to the time involved in the RVR-update computations. In the above, estimate for the time involved in the teletype operations, if any, is not included. The teletype speed and the number of characters in the output list determine the time involved.

TABLE D-2. ESTIMATES OF PROCESSOR TIME REQUIREMENTS FOR RVR UPDATE

Step		Time (s)	
No.	Description	Integer Arithmetic	Floating-Point Arithmetic
	Allard's Law using N-R iteration:		
1	(1) per iteration	0.01	0.03
	(2) for ten maximum iterations	0.10	0.30
2	Koschmieder's Law	0.003	0.011
	RVR Update		
3	(1) average (five iterations)	<0.05	0.15
	(2) maximum	0.1	0.30

D.5 PROGRAM SIZE

Table D-3 shows the size of the four basic programs that form part of the simulator software. VISIB updates and displays RVR based on the data from various sensors; ARITH provides the necessary integer arithmetic routines; TTYIO handles the teletype I/O operations and the related format conversion functions; and EXEC provides the control by keyboard commands. The total size of the program is 1754 memory locations. The routines in ARITH and TTYIO were specifically written to provide the necessary functions keeping the memory size requirements to a minimum. For a basic 4k memory configuration, room exists for further expansion of the program by about 1700 words, leaving aside about 600 words for interrupt vectors, stack requirements, and for the loaders.

TABLE D-3. SIZE OF THE PROGRAM SIMULATOR SOFTWARE

Program	Memory Size in Words	Comments
VISIB	887	RVR computations, I/O
ARITH	314	Arithmetic routines
TTYIO	388	Teletype I/O
EXEC	165	Executive
TOTAL	1754	

D.6 SIMULATOR SOFTWARE

```
       ;
       ;RVR VISIBILITY PROGRAMME
       ;
       ;SUBROUTINES:
       ;VISIB: MAIN PROGRAMME
       ;CALC:
       ;ITER:
       ;       ABOVE TWO SUPPLY NEW RVR VALUES
       ;FOLLOWING SERVICE OUTPUT PROVISIONS
       ;OUTPUT:        GENERAL ROUTINE
       ;OUTATC:        FOR VISUAL DISPLAY
       ;OUTREC:        TO TTY FOR RECORD
       ;STROBE:
       ;DISPLA:
       ;OUTSTR:
       ;       ABOVE THREE ARE AUXILLIARY OUTPUT ROUTINES
       ;FOLLOWING SERVICE INPUT PROVISIONS
       ;INPUT: GENERAL ROUTINE
       ;TTYDAT:DATA FROM TTY
       ;INTFAC:DATA FROM INTERFACE USING SUBROUTINES-
       ;       TRIN:   DATA FROM TRANSMISSOMETER COUNTERS

       ;       RINTIN: RUNWAY LIGHT SETTING
       ;       BGILIN: B/G ILLUMINANCE AND RUNWAY SELCTOR
       ;               SETTING
       ;TTYPAR:PARAMETER LIST FROM TTY
       ;
       ;LKSERV:KEEPS TRACK OF TIME(HR,MIN,SEC,ARCSEC),DAY
       ;       (DAY,MONTH,YEAR),START AND STOP PULSE COUNTERS,
       ;       AND CHECKS RUNWAY SELECTOR SWITCH SETTING EVERY
       ;       ONE SECOND.
       ;
       ;
       ;
       ;
       ;RUNWAY VISUAL RANGE PROGRAMME
000000 R0=%0
000001 R1=%1
000002 R2=%2
000003 R3=%3
000004 R4=%4
000005 R5=%5
000006 SP=%6
000007 PC=%7
       .GLOBL LSHIFT, SCALE,DIV,MULT,SCALOG,RSHIFT,MONDAY

       .GLOBL VISIB,THR,TMIN,TSEC,TDAY,TMON,TYEAR,MONDET,LKSERV


       .GLOBL GETCHR,GETNUM,ICA,ICABUF,INIT,MESS,PUTCHR,INBUF




       .TITLE VISIB
000000 .ASECT
```

```
                          PAGE    001

       005600 .=5600

005600 005067 CALC:    CLR ITRANS
       002750
005604 016700          MOV INTSTY,R0
       002674
005610 004567'         JSR R5.SCALOG
       000000
005614 010002          MOV R0,R2        ;SAVE
005616 016700          MOV ET,R0
       002664
005622 004567'         JSR R5.SCALOG    ;LOG(ET)*2**S
       000000
005626 160200          SUB R2.R0        ;2**S*(LOG(ET)-LOG(INTSTY))
005630 006200          ASR R0           ;DIVIDE BY 2
005632 166700          SUB L5280.R0
       002764
005636 010067          MOV R0,CAIK
       002732
005642 016700 CALBACK:         MOV ITRANS,R0
       002706
005646 006300          ASL R0
005650 016000          MOV NPUL(R0),R0
       010606
005654 004567          JSR R5.SCALOG    :2**S*LOG(NB)
       000000
005660 166700          SUB LOGNBM,R0    ;2**S*L0G(TB)
       002712
005664 010067          MOV R0,CAIB
       002702
005670 016700          MOV ITRANS,R0
       002660
005674 006300          ASL R0
005676 016067          MOV VSTORE(R0),V
       010602
       002674
005704 016767          MOV VINIT,V
       002702
       002666

005712 004567          JSR R5,ITER      ;SUPPLIES NEW RVR
       000032
005716 016700          MOV ITRANS,R0
       002632
005722 006300          ASL R0
005724 016760          MOV V,VSTORE(R0)         ;STORE NEW RVR
       002650
       010602
005732 005267          INC ITRANS
       002616
005736 026727          CMP ITRANS,#NTRANS
       002612


       000002
005744 002736          BLT CALBACK      :NO,GO BACK
005746 000205          RTS R5
```

```
              ;
              ;SUBROUTINE ITER
              ;SUPPLIES NEW RVR

              ;
005750 012767 ITER:MOV #1.NOITER
       000001
       002600
005756 004567         JSR R5.DPRNT1    ;DIAGNOSTIC PRINT ROUTINE
       000414



005762 016700 ITERLUP: MOV V.R0
       002612
005766 004567'        JSR R5.SCALOG    ;2**S*LOG(V)
       000000
005772 010067         MOV R0.ITIV      ;STORE
       002572
005776 016700         MOV V.R0
       002576

006002 016702         MOV CAIB.R2      ;V*LOG(TB)*2**S
       002564
006006 004567'        JSR R5.MULT
       000000
006012 016702         MOV BASE.R2
       002464
006016 006302         ASL R2

006020 004567'        JSR R5.DIV       ;R1=V*LOG(TB)*2**S/(BASE*2)
       000000

006024 160167         SUB R1.ITIV
       002540
006030 066767         ADD CAIK.ITIV    ;ITIV=CAIK+ITIV-R1
       002540
       002532
006036 015700         MOV MAGSCA.R0    ;MAGSCA=2**S
       002536
006042 160100         SUB R1.R0        :2**S-ITIV
006044 010067         MOV R0.DUM       :DUM=2**S-ITIV
       002516
006050 005767         TST MODNR
       002554
006054 001433         BEQ ITER10       ; MODNR IS A FLAG TO DECIDE IF MOD.
                                       ;N-R METHOD IS TO BE USED
              ;FOLLOWING CALCULATIONS ARE FOR MOD. N-R METHOD
              ;
006056 016700         MOV MAGSCA.R0    :2**S


       002536
006062 016702         MOV ITIV.R2      ;F(V)*2**S
       002502
006066 004567'        JSR R5.MULT
       000000
```

```
                      PAGE    003
006072 016702         MOV DUM,R2      ;F'(V)*V*2**S
       002470
006076 004567'        JSR R5.DIV      ;2**S*F*(2**S)/(2**S*F'*V)=R1
       000000
006102 026727         CMP MODNR,#1    ;MODNR=1:MOD. N-R METHOD
       002522
       000001
                                      ;     =2:HALLEY'S METHOD
006110 001401         BEQ ITER11

006112 006201         ASR R1          ;DIVIDE BY 2


006114 016700 ITER11: MOV DUM,R0
       002446
006120 006200         ASR R0
006122 020100         CMP R1.R0       ;R1<DUM/2?
006124 003004         BGT ITER8       ;IF NOT JUMP
006126 005400         NEG R0
006130 020100         CMP R1,R0       ;R1>-DUM/2?
006132 002401         BLT ITER8       ;IF NOT JUMP
006134 000401         BR ITER9
006136 010001 ITER8:  MOV R0.R1       ;SET THE APPROPRIATE
                                      ;VALUE FOR R1
006140 060167 ITER9:  ADD R1.DUM      ;REVISE DUM
       002422
              ;
              ;END OF SPECIAL CALCULATIONS FOR MOD.
              ;N-R METHOD

006144 016700 ITER10: MOV V,R0
       002430
006150 016702         MOV ITIV,R2
       002414

006154 004567'        JSR R5.MULT     ;(R0,R1)=V*ITIV
       000000
006160 016702         MOV DUM,R2
       002402
006164 004567'        JSR R5.DIV      ;R1=DELV=V*ITIV/DUM
       000000


006170 005701         TST R1

006172 016700         MOV V,R0
       002402
006176 160100         SUB R1,R0       ;VNEW=V-DELV
006200 020027         CMP R0,#VMAX    ;VNEW<VMAX?
       013560
006204 003402         BLE ITER1       ;YES.SKIP
006206 012700         MOV #VMAX,R0    ;VNEW=VMAX


       013560
006212 020027 ITER1:  CMP R0,#VMIN
       000062
006216 002002         BGE ITER2
```

```
006220 012700           MOV #VMIN,R0      ;VNEW=VMIN IF VNEW<VMIN
       000062
006224 010067 ITER2: MOV R0,V ;V=VNEW
       002350
006230 016702           MOV MEXIT,R2
       002372
006234 006200 ITER3:ASR R0
006236 005302           DEC R2
006240 001375           BNE ITER3
006242 005700           TST R0
006244 100002           BPL ITER4
```

```
006246 012700           MOV#1,R0           :EXIT= 1,IF V/2**MEXITIS ZERO OR
       000001
                                           ; LESS THAN ZERO
006252 005701 ITER4: TST R1
006254 100001           BPL ITER5
006256 005401           NEG R1
006260 004567 ITER5:    JSR R5,DPRNT2      :DIAGNOSTIC PRINT
       000132


005264 020100           CMP R1,R0          :DELV<V/2**SCALE?

006266 003407           BLE ITEREXIT       :YES,DONE,EXIT
006270 026727           CMP NOITER,#ITERMAX      :NOITER .GT. ITERMAX?
       002262
       000012
006276 003021           BGT ITERERR        :YES,PRINT MESSAGE,EXIT
006300 005267           INC NOITER
       002252


006304 000626           BR ITERLUP         :LOOP BACK
006305 016700 ITEREXIT:MOV BALEPS,R0
       002250
006312 016701           MOV BALEPS+2,R1
       002246
006316 016702           MOV CAIB,R2
       002250
006322 004567'          JSR R5,DIV
       000000
006326 020167           CMP R1,V
       002246
006332 002402           BLT ITER6
006334 010167           MOV R1,V           :NEW RVR IS AS CALCULATED BY KOSCHMEIDER
       002240
                                           :LAW, SINCE IT IS GREATER THAN THAT CALC
                                           :ULATED BY ALLARD'S LAW.

006340 000205 ITER6:    RTS R5

006342 010445 ITERERR: MOV R4,-(SP)
006344 012704           MOV #ITERMES,R4
       006360
006350 004567'          JSR R5,MESS
       000000
006354 012604           MOV (SP)+,R4
006356 000753           BR ITEREXIT
006360    015 ITERMES:.BYTE 15,12
006361    012
006362    115           .ASCII /MAX ITER/
006363    101
006364    130


006365    040
006366    111
006367    124
006370    105
```

```
006371     122
006372     015 ITCRLF: .BYTE 15,12,0
006373     012
006374     000
       006376          .EVEN
               ;
               ;DIAGNOSTIC PRINTOUT ROUTINE
               ;
006376 005767 DPRNT1:  TST DIAGNO      ;ANY DIAGNOSTIC?
       002212
006402 001404          BEQ DPR1
006404 012704          MOV #ITMESS,R4
       006446
006410 004567'         JSR R5,MESS
       000000
006414 000205 DPR1:    RTS R5
               ;
006416 005767 DPRNT2:  TST DIAGNO      ;ANY DIAGNOSTICS?
       002172 .
006422 001410          BEQ DPR2
006424 010167          MOV R1,DUM
       002136
006430 004567'         JSR R5,ICABUF   ;SET UP OUTPUT LIST
       000000
006434 000003          .WORD 3
006436 010600          .WORD V,ITIV,DUM
006440 010570
006442 010566
006444 000205 DPR2:    RTS R5
               ;
               ;
006446     015 ITMESS: .BYTE 15,12
006447     012
006450     126         .ASCII /V          F(V)
006451     040
006452     040
006453     040
006454     040
006455     040
006456     040
006457     040
006460     040
006461     040
006462     106
006463     050
006464     126
006465     051
006466     040
006467     040
006470     040
006471     040
006472     040


006473     040
006474     104         .ASCII /DELV/
006475     105
006476     114
```

```
                    PAGE    007

006477     126
006500     015          .BYTE 15,12,0
006501     012
006502     000
       006504           .EVEN
                ;
                ;
                ;
                ;SUBROUTINE OUTPUT
                ;
006504 010246 OUTPUT:MOV R2,-(SP)
006506 010346         MOV R3,-(SP)
006510 010446         MOV R4,-(SP)
006512 004567         JSR R5,OUTATC    ;AIR TRAFFIC CONTROL DISPLAY
       000014
006516 004567         JSR R5,OUTREC    ;RECORDING ROUTINE
       000024
006522 012604         MOV (SP)+,R4
006524 012603         MOV (SP)+,R3
006526 012602         MOV (SP)+,R2
006530 000205         RTS R5
                ;
                ;AIR TRAFFIC CONTROL DISPLAY ROUTINE
                ;


006532 005767 OUTATC: TST INMODE
       001754
006536 001402         BEQ OUTA1
006540 004567         JSR R5,OUTSTR
       001542
006544 000205 OUTA1:  RTS R5
                ;
                ;RECORDS INFORMATION-HERE ON TTY
                ;
006546 012704 OUTREC: MOV #OUTMES,R4
       006502

006552 004567'        JSR R5,MESS
       000000
006556 004567'        JSR R5,ICABUF
       000000
006562 000006         .WORD 6.,ET,INTSTY,NPUL,VSTORE,NPUL+2
006564 010506
006566 010504
006570 010606
006572 010502
006574 010610
006576 010604         .WORD VSTORE+2
006600 000205         RTS R5
                ;



006602     015 OUTMES: .BYTE 15,12
006603     012
006604     105          .ASCII /ET        I          NPUL1
```

```
006605    124
006606    040
006607    040
006610    040
006611    040
006612    040
006613    040
006614    040
006615    040
006616    111
006617    040
006620    040
006621    040
006622    040
006623    040
006624    040
006625    040
006626    040
006627    040
006630    116
006631    120
006632    125
006633    114
006634    061
006635    040
006636    040
006637    040
006640    040
006641    040
006642    122         .ASCII /RVR1      NPUL2      RVR2/
006643    126
006644    122
006645    061
006646    040
006647    040
006650    040
006651    040
006652    040
006653    040
006654    116
006655    120
006656    125
006657    114
006660    062
006661    040
006662    040
006663    040
006664    040
006665    040
006666    122
006667    126
006670    122

006671    062
006672    015         .BYTE 15,12,0
006673    012
006674    000
```

```
          006676        .EVEN

                   ;ROUTINE SERVES LINE CLOCK INTERRUPT
                   ;KEEPS TRACK OF TIME,AND DATE
                   ;STARTS AND STOPS PULSE COUNTERS

                   ;CHECKS RUNWAY SELECTOR SWITCH EVERY ONE SECOND
                   ;;
                   ;
006676 005767 LKSERV:TST CTRFLG
       001620
                                  ;TIME WINDOW TO BE INITIATED?
006702 001411           BEQ LK1

006704 016767           MOV TW,TWCTR
       001620
       001620
                                  ;TW=T*60,T=TIME WINDOW IN SECS
006712 110037 .         MOVB R0,@#164000
       164000
                                  ;ENABLE AND RESET C/T COUNTER TO
                                  ;ZERO
006716 005067           CLR CTRFLG
       001600
                                  ;CLEAR FLAGS
006722 005067           CLR INFLAG
       001576

006726 005367 LK1:      DEC TWCTR
       001600
006732 001004           BNE LK2
006734 110037           MOVB R0,@#164001
       164001



                                             ;DIENABLE  C/T COUNTER

006740 005267           INC INFLAG
       001560
                                  ;FLAG TO SIGNIFY READING DONE
005744 005267 LK2:      INC TARSEC
       001564
006750 026727           CMP TARSEC,#60.
       001560
       000074
006756 001401           BEQ LK3
006760 000002           RTI
                   ;ENTERED EVERY 1 SECOND
006762 005067 LK3:      CLR TARSEC
       001546
006766 005267           INC TSEC


       001544
006772 026727           CMP TSEC,#60.
       001540
       000074
```

```
                              PAGE    012
007000 002452                 BLT LK9
007002 005067                 CLR TSEC
       001530
007006 005267                 INC TMIN
       001526
007012 026727                 CMP TMIN,#60.
       001522
       000074
007020 002442                 BLT LK9
007022 005067                 CLR TMIN
       001512
007026 005267                 INC THR
       001510
007032 026727                 CMP THR,#24.
       001504
       000030
007040 002432                 BLT LK9

007042 005067 .               CLR THR
       001474
007046 005267                 INC TDAY
       001472
007052 026767                 CMP TDAY,MONDAY
       001466
       001466
007060 002422                 BLT LK9
007062 012767                 MOV #1,TDAY
       000001
       001454
007070 005267                 INC TMON
       001454
007074 026727                 CMP TMON,#13.
       001450
       000015
007102 002405                 BLT LK8
007104 012767                 MOV #1,TMON
       000001
       001436


007112 005267                 INC TYEAR
       001434
007116 016645 LK8:            MOV 2(SP),-(SP)
       000002
007122 012746'                MOV #MONDET,-(SP)
       000000
007126 005767 LK9:            TST INMODE
       001360

007132 001001                 BNE LK4
007134 000002                 RTI

007136 010046 LK4:            MOV R0.-(SP)
007140 010146                 MOV R1.-(SP)
007142 016700                 MOV RSELECT,R0
       001360
```

```
                              ;INTERFACE MODE
007146 005067         CLR RSELECT
       001354
007152 113701         MOVB @#164004,R1
       164004
                              ;WORD CONTAINING R/SETTING BIT
007156 106001         RORB R1
007160 005567         ADC RSELECT
       001342
007164 012601 LK5:    MOV (SP)+,R1    ;CHECK IF
007166 026700         CMP RSELECT,R0  ;STATUS OF FLAG
       001334
007172 001002         BNE LK7         ;IS CHANGED
007174 012600         MOV (SP)+,R0    ;IF NOT RETURN
007176 000002         RTI
007200 012600 LK7:    MOV (SP)+,R0
007202 016646         MOV 2(SP),-(SP) ;MOVE PROCESSOR STATUS OF INTERRUPTED
       000002
                                      ;PROGRAMME TO STACK
007206 012746         MOV #STROBE,-(SP)
       010300
                                      ;STATUS OF RFLAG
007212 000002         RTI             ;PUSH ADDRESS OF STROBE
                                      ;ROUTINE AND OLD PSWORD
                                      ;ON THE STACK IN THAT ORDER
              ;INPUT ROUTINE FOR PROGRAMME
              ;
007214 005767 INPUT: TST INMODE       ;CHECK INPUT MODE
       001272
007220 001403         BEQ INTTY               ;BRANCH IF TTY MODE
007222 004567         JSR R5,INTFAC           ;INTERFACE MODE
       000602
007226 000205         RTS R5
007230 004567 INTTY: JSR R5,TTYDAT    ;DATA COMES FROM TTY
       000002
007234 000205         RTS R5
                                      ;IN THE ARRAY
              ;
              ;
              ;SUBROUTINE TTYDAT
              ;TAKES DATA FROM TTY
007236 004567 TTYDAT: JSR R5,SPACE
       000532
007242 000001         .WORD 1


007244 004567         JSR R5,INBUF
       000000
007250 000004         .WORD 4
007252 007274         .WORD MWORD6,INTSTY     ;INTENSITY OF RUNWAY LIGHTS
007254 010504


007256 007304         .WORD MWORD7,ET         ;ILLUMINANCE THRESHOLD
007260 010506
007262 007310         .WORD MWORD8,NPUL       ;PULSE COUNT FOR C/T TR
007264 010606
```

```
                          PAGE    014
007266 007320          .WORD MWORD9,NPUL+2      ;PULSE COUNT FOR BCD INPUT TR
007270 010610

007272 000205 RTS R5
              ;
007274    111 MWORD6: .ASCII /INTSTY=/
007275    116
007276    124
007277    123
007300    124
007301    131
007302    075
007303    000 .BYTE 0
       007304 .EVEN
007304    105 MWORD7: .ASCII /ET=/
007305    124
007306    075
007307    000 .BYTE 0
       007310 :EVEN
007310    116 MWORD8: .ASCII /NPUL1=/
007311    120
007312    125
007313    114
007314    061
007315    075
007316    000          .BYTE 0
       007320 .EVEN
007320    116 MWORD9: .ASCII /NPUL2=/
007321    120
007322    125
007323    114
007324    062
007325    075
007326    000 .BYTE 0
       007330 .EVEN
              ;
              ;
              ;SUBROUTINE TTYPAR
              ; SUPPLIES PARAMETERS-BASIC;
007330 004567 TTYPAR: JSR R5,SPACE
       000440
007334 000005          .WORD 5

007336 004567'         JSR R5,INBUF
       000000
007342 000003          .WORD 3
007344 007744          .WORD NWORD1,SCALE
007346 010616
007350 007754          .WORD NWORD2,MEXIT
007352 010626
007354 007764          .WORD NWORD3,DIAGNO

007356 010614
```

```
007360 012700           MOV *1,R0
       000001

007364 016701           MOV SCALE,R1
       001226
007370 004567'          JSR R5,LSHIFT
       000000
007374 010067           MOV R0,MAGSCA    ;MAGSCA=2**SCALE
       001220
007400 012700           MOV *5280.,R0    ;MILE
       012240
007404 004567'          JSR R5,SCALOG
       000000

007410 010067           MOV R0,L5280     ;L5280=LOG10(5280)*2**SCALE
       001206
007414 012700           MOV *20627.,R0
       050223



007420 012701           MOV *14.,R1      ;-20627.=LOG10(EPS=.055)*2**15
       000016
007424 166701           SUB SCALE,R1
       001166

007430 004567'          JSR R5,RSHIFT    ;RIGHT SHIFT ROUTINE
       000000
Q
007434 005400           NEG R0

007436 010067           MOV R0,LEPS      ;LEPS=LOG10(EPS)*2**SCALE
       001162


007442 004567'TTYPA4: JSR R5,INBUF
       000000
007446 000005           .WORD 5
007450 007706           .WORD MWORD1,VINIT
007452 010612
007454 007712           .WORD MWORD2,BASE
007456 010502
007460 007720           .WORD MWORD3,PRATE
007462 010510
007464 007730           .WORD MWORD4,TW
007466 010530
007470 007734           .WORD MWORD5,INMODE
007472 010512
              ;
007474 016767           MOV VINIT,VSTORE
       001112
       001100


007502 016767           MOV VINIT,VSTORE+2
       001104
       001074
007510 016702           MOV PRATE,R2
       000774
```

```
                      PAGE    016

007514 016700         MOV TW,R0
       001010
007520 004567'        JSR R5,MULT
       000000
007524 010100         MOV R1,R0       ;MAX PULSE COUNT
007526 004567'        JSR R5,SCALOG
       000000
007532 010067         MOV R0,LOGNBM
       001040
007536 016700         MOV TW,R0
       000766
007542 012702         MOV #60.,R2
       000074
007546 004567         JSR R5,MULT
       000000
007552 010167         MOV R1,TW       ;NOW TW=TW*60
       000752
007556 016700         MOV BASE,R0
       000720
007562 016702         MOV LEPS,R2
       001036
007566 004567         JSR R5,MULT
       000000
007572 010067         MOV R0,BALEPS
       000764
007576 010167         MOV R1,BALEPS+2         ;STORE BASE*LOG10(EPS=.05)*2**5
       000762
                                              ;AT BALEPS IN DOUBLE PRECISION

007602 005267         INC FSTIME
       000712
007606 012767 TTYPA3: MOV #NINPUT,NCOUNT
       000005
       000702

007614 005767 TTYPA1: TST NCOUNT
       000676

007620 001401         BEQ PBACK
007622 000205         RTS  R5
007624 012704 PBACK: MOV #PARMES,R4
       007656
007630 004567'        JSR R5,MESS
       000000
007634 004567'        JSR R5,GETCHR
       000000
007640 120027         CMPB R0,#131
       000131

007644 001676         BEQ TTYPA4
007646 000757         BR TTYPA3


              ;
007650 005367 TTYPA2: DEC NCOUNT
       000642
007654 000757         BR TTYPA1
```

```
                        ;
007656     015 PARMES: .BYTE 15,12
007657     012
007660     120         .ASCII /PARAMETER CHANGE ?/
007661     101
007662     122
007663     101
007664     115
007665     105
007666     124
007667     105
007670     122
007671     040
007672     103
007673     110
007674     101
007675     116
007676     107
007677     105
007700     040
007701     077
007702     015         .BYTE 15,12,0
007703     012
007704     000
        007706         .EVEN
007706     126 MWORD1: .ASCII /VI=/
007707     111
007710     075
007711     000         .BYTE 0
        007712         .EVEN
007712     102 MWORD2: .ASCII /BASE=/
007713     101
007714     123
007715     105
007716     075
007717     000         .BYTE 0
        007720         .EVEN
007720     120 MWORD3: .ASCII /PRATE=/
007721     122
007722     101
007723     124
007724     105
007725     075
007726     000         .BYTE 0
        007730         .EVEN
007730     124 MWORD4: .ASCII /TW=/
007731     127
007732     075
007733     000         .BYTE 0
        007734         .EVEN
007734     111 MWORD5: .ASCII /INMODE=/
007735     116


007736     115
007737     117
007740     104
007741     105
```

```
007742    075
007743    000          .BYTE 0
       007744          .EVEN
007744    123 NWORD1: .ASCII   /SCALE=/
007745    103
007746    101
007747    114
007750    105
007751    075
007752    000          .BYTE 0
       007754          .EVEN
007754    105 NWORD2: .ASCII /EXITSC=/
007755    130
007756    111
007757    124
007760    123
007761    103
007762    075.
007763    000          .BYTE 0

007764    104 NWORD3: .ASCII /DIAGNO=/
007765    111
007766    101
007767    107
007770    116
007771    117
007772    075
007773    000          .BYTE 0
       007774          .EVEN
       007774          .EVEN
                  ;
                  ;
                  ;THIS SUBROUTINE MAKES TELEPRINTER
                  ;ADVANCE BY ONE LINE
                  ;
007774 010146 SPACE:  MOV R1,-(SP)
007776 010446         MOV R4,-(SP)
010000 012501         MOV (R5)+,R1
010002 012704 SPABAC: MOV #SPCRLF,R4
       010024
010006 004567'        JSR R5,MESS
       000000
010012 005301         DEC R1
010014 001372         BNE SPABAC
010016 012604         MOV (SP)+,R4
010020 012601         MOV (SP)+,R1

010022 000205         RTS R5
010024    015 SPCRLF: .BYTE 15,12,0
010025    012
010026    000


       010030          .EVEN
                  ;

                  ;
```

```
                     ;;SUBROUTINE INTFAC
                     ;ACEPTS DATA FROM INTERFACE
                     ;
010030 004567 INTFAC:JSR R5,TRIN        ;INPUTS FROM TRANS. COUNTERS
       000012
010034 004567         JSR R5,RINTIN     ;RUNWAY LIGHT INTESITY ROUTINE
       000112
010040 004567         JSR R5,BGILIN     ;BACKGROUND ILLUMINANCE AND RUNWAY
       000150
                                        ;SELCTOR SWITCH POSITION.

010044 000205         RTS R5
                     ;
                     ;
                     ;TRANSMISSOMETER COUNT INPUT ROUTINE
010046 005767 TRIN: TST FSTIME          ;FIRST TIME WINDOW
       000446
010052 001407         BEQ IOD3          ;IF NOT JUMP
010054 005067         CLR FSTIME        ;CLEAR FLAG
       000440
010060 005267         INC CTRFLG        ;SIGNAL TO INTERRUPT ROUTINE TO START
       000436
                                        ; TIME WINDOW
010064 005767 IOD4:   TST CTRFLG        ;HAS IT STARTED?
       000432
010070 001375         BNE IOD4          ;IF NOT WAIT
010072 005767 IOD3:   TST INFLAG        ;TIME WINDOW OVER?
       000426
010076 001775         BEQ IOD3          ;IF NOT WAIT
010100 013767         MOV @#164000,NPUL         ;READ COUNT DURING TIME WINDOW
       164000
       000500
                                        ;
010106 112700         MOVB #046,R0      ;ASCII CODE FOR &
       000046
010112 004567'        JSR R5,PUTCHR     ;PUT IT ON KB
       000000
010116 004567'        JSR R5,GETCHR     ;PROGRAMME STALLS HERE TILLIT SEES
       000000
                                        ;ANY INPUT FROM KB. DURING THIS STALL
                                        ;PHASE,SWITCH SETTINGS ON INTERFACE
                                        ;MAY BE CHANGED.

010122 005267         INC CTRFLG
       000374
010126 005767 IOD1:   TST CTRFLG        ;HAS THE TIME WINDOW BEEN STARTED?
       000370
010132 001375         BNE IOD1                  ;IF NOT WAIT
                     ;
010134 005737 IOD7:   TST @#164002      ;WORD 2 READY?
       164002
010140 100775         BMI IOD7

010142 013767         MOV @#164002,NPUL+2
       164002
       000440
010150 000205         RTS R5
```

```
                ;
                ;RUNWAY LIGHT INTENSITY INPUT ROUTINE
                ;


010152 005737 RINTIN: TST @#164004     ;CHECK IF WORD 3 READY?
       164004
010156 100775         BMI RINTIN       ;NO,WAIT
010160 113700         MOVB @#164005,R0          ;HIGHER BYTE
       164005
010164 012701         MOV #3,R1        ;COUNTER
       000003
010170 106200 IOD9:   ASRB R0
010172 103002         BCC IOD10
010174 005301         DEC R1
010176 000774         BR IOD9
010200 006301 IOD10:  ASL R1
010202 016167         MOV INTTBL(R1),INTSTY
       010260 .
       000274
010210 000205         RTS R5
                ;
                ;ROUTINE SUPPLIES:(1)VISUAL ILLUMINANCE THRESHOLD OF PILOT
                ;                 (2)RUNWAY SELECTOR SWITCH SETTING -FOR RVR
010212 010332                      DISPLAY
                ;

010214 005067 BGILIN: CLR RSELECT
       000306
010220 113700         MOVB @#164004,R0
       164004
010224 106200         ASRB R0
010226 005567         ADC RSELECT
       000274
010232 106300         ASLB R0
010234 005001         CLR R1
010236 106300 IOD11:  ASLB R0
010240 103002         BCC IOD12
010242 005201         INC R1
010244 000774         BR IOD11
010246 006301 IOD12:  ASL R1
010250 016167         MOV ETTBL(R1),ET
       010270
       000230
010256 000205         RTS R5

010260 000620 INTTBL: .WORD 400.,2000.,10000.,20000.
010262 003720
010264 023420
010266 047040
010270 000002 ETTBL:  .WORD 2,26.,260.,2600.
010272 000032


010274 000404
010276 005050
                ;
                ;STROBE ROUTINE
```

```
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                 ;SERVICES TIME INTERRUPT ROUTINE LKSERV AT PROGRAMME
                 ;INTERRUPT LEVEL
010300 004567 STROBE: JSR R5,OUTSTR
       000002
010304 000002         RTI
                 ;
                 ;
                 ;OUTSTR ROUTINE STROBES THE RVR FOR
                 ;THE RUNWAY CORRESPONDING TO THE ONE
                 ;REQUESTED BY THE RUNWAY SELECTOR SWITCH
                 ;


                 ;
                 ;
010306 010046 OUTSTR: MOV R0,-(SP)
010310 016700         MOV RSELECT,R0
       000212
010314 006300         ASL R0

010316 016000         MOV VSTORE(R0),R0
       010602
010322 004567         JSR R5,DISPLA
       000004
010326 012600         MOV (SP)+,R0
010330 000205         RTS R5

                 ;
                 ;
                 ;
                 ;DISPLA ROUTINE
                 ;STROBES NO IN R0 TO DISPLAY
                 ;IF NO IS GREATER THAN 9998. ,9998. IS DISPLAYED
                 ;IF NI IS - , 9999 IS DISPLAYED
                 ;
010332 010146 DISPLA: MOV R1,-(SP)
010334 010246         MOV R2,-(SP)
010336 010346         MOV R3,-(SP)
010340 010446         MOV R4,-(SP)
010342 020027         CMP R0,#9998.
       023416
010346 003042         BGT DISPL3
010350 005700         TST R0
010352 100443         BMI DISERR
010354 012702 DISPL4: MOV #BUFFIC,R2
       010470
010360 004567'        JSR R5,ICA       ;BINARY TO ASCII
       000000
010364 012704         MOV #BUFFIC+2,R4         ;SKIP SIGN BYTE AND LEADING DIGI
       010472
                 ;                   BYTE
010370 012703         MOV #2,R3


       000002
010374 112400 DISPL1: MOVB (R4)+,R0    ;HIGHER DIGIT
010376 162700         SUB #60,R0       ;CONVERT TO BINARY
       000060
```

```
010402 110001           MOVB R0,R1
010404 112400           MOVB (R4)+,R0   ;GET NEXT LOWER DIGIT
010406 162700           SUB #60,R0      ;CONVERT TO BINARY
       000060
010412 006300           ASL R0
010414 006300           ASL R0
010416 006300           ASL R0
010420 006300           ASL R0  ;SHIFT LEFT 4 TIMES
                        ;THE LOWER DIGIT IS NOW IN RIGHT HALF OF LOW BYTE OF R0
010422 060100           ADD R1,R0       : FORM A BYTE OF TWO DIGITS
010424 005303           DEC R3
010426 001403           BEQ DISPL2      ;JUMP ON SECOND PASS
010430 110037           MOVB R0,@#164006        ;ON FIRST PASS STROBE TOP TWO
       164006
                        ;DIGITS TO DISPLAY
010434 000757           BR DISPL1
010436 110037 DISPL2:   MOVB R0,@#164007
       164007
                        ;PASS TWO LOWER DIGITS ARE STROBED TO DISPLAY
010442 012604           MOV (SP)+,R4
010444 012603           MOV (SP)+,R3
010446 012602           MOV (SP)+,R2
010450 012601           MOV (SP)+,R1
010452 000205           RTS R5
010454 012700 DISPL3:MOV #9998.,R0      ;LIMIT NO TO 9998.
       023416
010460 000735           BR DISPL4
010462 012700 DISERR: MOV #9999. ,R0    ;IF NO IS - ,DISPLAY 99999
       023417
010466 000732           BR DISPL4
       010502 BUFFIC: .=.+10.
              ;
              ;.
              ;CONSTANTS FOR VISIB PROGRAMME
              ;
       000002           NTRANS=2        ;NO OF TRANS
       000004           NTRDBL=4        ;NTRANS*2


       000012           ITERMAX=10.     ;MAXIMUM NO OF ITERATIONS ALLOWED


       013560           VMAX=6000.      ;MAXIMUM RVR LIMIT TO
       000062           VMIN=50.        ;MINIMUM RVR LIMIT

       000005           NINPUT=5        ;TOTAL NO OF DATA INPUTS BEFORE PARAMETE
                                ;CHANGE CAN BE REQUESTED


              VARIABLES FOR VISIBILITY PROGRAMME


010502 000000 BASE:     .WORD 0
010504 000000 INTSTY:   .WORD 0
010506 000000 ET:       .WORD 0
010510 000000 PRATE:    .WORD 0
```

```
010512 000000 INMODE: .WORD 0
010514 000074 TCTR:   .WORD 60.
010516 000000 NCOUNT: .WORD 0
010520 000000 FSTIME: .WORD 0 ;FLAG IF FIRST TIME WINDOW
010522 000000 CTRFLG: .WORD 0 ;FLAG TO SIGNAL TIME INTERRUPT ROUTINE
                              ;TO START TIME WINDOW
010524 000000 INFLAG: .WORD 0 ;FLAG TO SIGNIFY TIME WINDOW IN PROGRESS
010526 000000 RSELECT: .WORD 0        ;FLAG TO INDICATE RUNWAY SELECTOR SWITCH
                      ;POSITION
010530 000000 TW:     .WORD 0 ;TIME WINDOW
010532 000000 TWCTR:  .WORD 0 ;TIME WINDOW COUNTER,DECREMENTED BY 1
                              ;EVERY 1/60 TH OF A SEC
010534 000000 TARSEC: .WORD 0
010536 000000 TSEC:   .WORD 0


010540 000000 TMIN:   .WORD 0 ;KEEPS TIME IN MINUTES
010542 000000 THR:    .WORD 0 ;
010544 000000 TDAY:   .WORD 0
010546 000040 MONDAY: .WORD 32.

010550 000000 TMON:   .WORD 0
010552 000000 TYEAR:  .WORD 0


010554 000000 ITRANS: .WORD 0 ;KEEPS TRACK OF NUMBER OF TRANS.
                              ;WHOSE INPUTS HAVE BEEN PROCESSED FOR RVR
010556 000000 NOITER: .WORD 0 ;NO OF ITERATIONS IN RVR CALCULATIONS
010560 000000 VNEW:   .WORD 0 ;TEMP STORAGE FOR RVR ITERATE
010562 000000 BALEPS: .WORD 0,0       ;STORAGE FOR D.PR. PRODUCT OF BASE*LOG10
010564 000000
                                      ;(.05)*2**S

010566 000000 DUM:    .WORD 0;TEMP
010570 000000 ITIV:   .WORD 0 ;TEMP


010572 000000 CAIB:   .WORD 0 ;TEMP
010574 000000 CAIK:   .WORD 0 ;TEMP
010576 000000 LOGNBM: .WORD 0 ;TEMP
010600 000000 V:      .WORD 0 ;TEMP
       010606 VSTORE:.=.+NTRDBL       ;STORAGE SPACE FOR RVR FOR DIFF TRS.
       010612 NPUL:   .=.+NTRDBL      ;STORAGE SPACE FOR
                                      ;COUNTER INPUTS FROM DIFFERENT TRS
010612 000000 VINIT:  .WORD 0 ;INITIAL VALUE OF RVR ITR
010614 000000 DIAGNO: .WORD 0 ;DIAGNO=1 FOR DIAGNOSTIC PRINT

010616 000011 SCALE:  .WORD 9.        ;SCALE FACTOR FOR INTEGER ARITHMETIC
010620 000000 MAGSCA: .WORD 0 ;=2**SCALE
010622 000000 L5280:  .WORD 0 ;STORES LOG10(5280.)*2**SCALE
010624 000000 LEPS:   .WORD 0 ;STORES LOG10(EPS=.05)*2**SCALE
010626 000000 MEXIT:  .WORD 0 ;EXIT SCALE FACTOR


010630 000000 MODNR:  .WORD 0 ;DETEMINES ITERATION METHOD TO SOLVE ALLARD'S LAW
                                      ;=0:N-R METHOD
                                      ;=1:MOD N-R METHOD
```

```
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                                          ;=2:HALLEY'S METHOD
                                          ;NORMALLY MODNR=0.IF HIGHER ORDER METHOD
                                          ;USED,APFROPRIATE VALUES SHOULD BE TOGG
                                          ;-LED IN FROM
                                          ;SWITCH BOARD
                    ;
                    ;
                    ;

                    ;
                    ;VISIBILITY PROGRAMME
                    ;
                    ;
010632 004567'VISIB:  JSR R5,INIT         ;INITIALIZE
       000000


010636 004567         JSR R5,TTYPAR       ;PARAMETEREINPUT FROM TTY
       176466
010642 004567 VISLUP: JSR R5,INPUT        ;DATA INPUT FROM TTY OR INTERFACE
       176346

                                          ;DEPENDING UPON INPUT MODE
010646 004567         JSR R5,CALC         ;PROCESSES DATA INPUTS TO PRODUCE
       174726

                                          ;RVR VALUES
010652 004567         JSR R5,OUTPUT       ;OUTPUTS RVR AND ASSOCIATED DATA
       175626
010656 004567         JSR R5,TTYPA2       ;CHECKS ONCE EVERY NINPUT TIMES
       176766

                                          ;IF NEW SET OF PARAMETERS ARE TO BE INPU
010662 000767         BR VISLUP           ;BACK FOR MORE DATA INPUT
                                          ;NEED TO BE CHANGED ;IF SO IT
                                          ;LOOPS BACK TO TTYPAR BY ITSELF
010664 000000         HALT

                    ;
       010632         .END VISIB











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000001 ERRORS
```

```
             ;
             ;
             ;TTY I/O PACKAGE AND EXECUTIVE
             ;
             ;SUBROUTINES:
             ;      EXECUT: EXECUTIVE PROGRAMME TO MONITOR
             ;              THE PROGRAMMME DURING RUN-TIME.

             ;
             ;              PROGRAMME ENTERED BY CONTROL C KEY INPUT
             ;              FROM TTY KB.EXECUTIVE CAN RESPOND TO A SET OF
             ;              COMMANDS DESCRIBED BELOW. COMMANDS ARE INPUT
             ;              FROM KB;AND ARE TWO CHS LONG TERMINATED
             ;              BY EITHER A CR OR COMMA.ANY OTHER TERMINATING
             ;              CHARACTER IS NOT VALID. FOR INVALID CHS. ,'?'IS
             ;              PRINTED ON TTY AND A FRESH STRING OF COMMAND CHS
             ;              CAN BE INPUT.
             ;
             ;              COMMAND STRINGS:
             ;
             ;              (1) CO  CONTINUE WITH THE PROGRAMME WHERE IT WAS
             ;              INTERRUPTED.
             ;              (2) AR  GO TO ARITHMETIC PACKAGE TEST ROUTINE
             ;               ARTEST.
             ;              (3) IO  GO TO TTY I/O PACKAGE TEST ROUTINE
             ;               IOTEST.
             ;              (4) RE  RESTART VISIBILITY PROGRAMME.
             ;              (5) TI  TIME COMMAND
             ;                      IF TERMINATED BY CR.PRINTS TIME IN HR
             ;                      ,MIN,SEC AND CONTINUES WITH THE
             ;                      INTERRUPTED PROGRAMME.

             ;
             ;                      IF TERMINATED BY COMMA, ACCEPTS FROM KB
             ;                      HR,MIN,SECS IN 3(I-) FORMAT DESCRIBED
             ;                      BELOW.THEN INTERRUPTED PROGRAMME
             ;                      IS RESUMED.
000000 000000'.
             ;                      (6) DA  DATE COMMAND
             ;                              IF TERMINATED BY CR.PRINTS DATE
             ;                              AS DAY ,MONTH,YEAR AND CONTINUES
             ;                              PROGRAMME.
             ;
             ;                              IF TERMINATED BY COMMA, ACCEPTS
             ;                              DAY,MONTH,YEAR IN (3I-)FORMAT,
             ;                              AND CONTINUES WITH INTERRUPTED
             ;                              PROGRAMME.
             ;
             ;
             ;
             ;      IOTEST: TEST ROUTINE FOR TTY I/O PACKAGE
             ;      INIT:   INITIALIZATION,ENABLE
             ;              INTERRUPTS OF PERIPHERALS,SET UP
             ;              STACK AREA,SET UP SERVICING ROUTINES


             ;              FOR INTERRUPT VECTORS.
             ;      GETCHR: GET A CHARACTER FROM TTY KB BUFFER
```

```
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       ;       PUTCHR: PRINT A CHARACTER ON TTY
       ;       LINE:   ASSEMBLE A STRING OF CHARACTERS FORM TTY
       ;               TERMINATED BY CR OR COMMA.EDITING PROVISION
       ;               BY RUBOUT KEY AND DELETING OF CHARACTER STRING
       ;               INPUT SO FAR BY CONTROL SHIFT K AND CONTROL U
       ;               KEY INPUTS IS PROVIDED.CHARACTERS ARE APPROPRIAT
       ;               ECHOED ON TTY.
       ;       GETNUM: ACCEPTS A + INTEGER FROM TTY AND ASSEMBLES
       ;               A BINARY NO.INPUT FORMAT IS I-
       ;               WHERE I- SIGNIFIES A VARIABLE I FORMAT
       ;               WITH INPUT TERMINATED EITHER BY A COMMA OR CR
       ;               PROGRMME PERSISTS TILL A VALID + INTEGER
       ;               <2**15-1 AND WITH NO NON-NUMERIC CHS IS
       ;               INPUT
       ;       ICABUF: PRINTS OUTPUT LIST A1,A2,.....,AN ON TTY
       ;               FORMAT(/N(2X,I6,4X))
       ;       ICA:    AASEMBLES AN OUTPUT FORMAT(6I,4X)
       ;               WHERE I FORMAT HAS A LEADING SIGN
       ;               AND FIVE DIGITS CORRESPONDING TO A
      .;               GIVEN BINARY NUMBER.
       ;       INBUF: ACCEPTS FROM TTY INPUT LIST
       ;               A1,A2,....,AN WITH FORMAT
       ;               ($MES1$,I-,$MES2$,I-,.....$MESN$,I-)
       ;       IBUFER: ACCEPTS FROM TTY INPUT LIST
       ;               A1,A2,....,AN IN THE FORMAT
       ;               (NI-)
       ;       RDRINT: SERVICES TTY KB INTERRUPT
       ;;
       ;
       ;


000000         R0=%0
000001 R1=%1
000002 R2=%2
000003 R3=%3
000004 R4=%4
000005 R5=%5
       .GLOBL GETCHR,GETNUM,ICA,ICABUF,INIT,MESS,PUTCHR,LINE,INBUF
       .GLOBL VISIB,IOTEST,ARTEST,THR,TMIN,TSEC,TDAY,TMON,TYEAR
       .GLOBL MONDET,MONDAY,LKSERV



000006 SP=%6
000007 PC=%7
       .TITLE IOTEST

000000 .ASECT
002000 .=2000
       ;


       ;TTY I-O PACKAGE TEST PROGRAMME
       ;SHOULD DO THE FOLLOWING:
       ;1)PRINT 'VALUE=' ON TTY
       ;2)ACCEPT + INTEGER<2**15-1 FROM TTY KB
```

```
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              ;3)PRINT NUMBER SO INPUT ON TTY
              ;

002000 004567 IOTEST: JSR R5,INIT
       000046




002004 004567 MAINBAC:        JSR R5,INBUF
       001140
002010 000001         .WORD 1
002012 002032         .WORD MAINMES,MAINBUF
002014 002044

002016 004567         JSR R5,ICABUF
       000674
002022 000001         .WORD 1.,MAINBUF
002024 002044
002026 000766         BR MAINBAC
002030 000000         HALT
002032    015 MAINMES:.BYTE 15,12
002033    012
002034    126         .ASCII /VALUE=/
002035    101
002036    114
002037    125
002040    105
002041    075
002042    000         .BYTE 0
       002044         .EVEN
002044 000000 MAINBUF:        .WORD 0,0
002046 000000
002050    000                 .BYTE 0
       002052                 .EVEN
              ;
              ;TTY IO PACKAGE
              ;--------------
              ;
              ;
              ;SUBROUTINE INIT
              ;SHOULD BE INCORPORATED IN THE PROGRAMME BEFORE ANY I/O
              ;OPERATIONS IN THE MAIN PROGRAMME
              ;
002052 012706 INIT:   MOV #1000,SP    ;STACK ADDRESS
       001000
002056 012737         MOV #LKSERV,@#100       ;LINE CLOCK INTERRUPT
       000000
       000100
                                      ;VECTOR
002064 012737         MOV #300,@#102          ;PROCESSOR STATUS
       000300


       000102
002072 012737         MOV #100,@#177546       ;ENABLE LINE CLOCK
       000100
       177546
```

```
                      PAGE    003

002100 012737         MOV #RDRINT,@#60        ;READER INTERRUPT SERVICE ROUTIN
       003256
       000060
002106 012737         MOV #200,@#62           ;INTERRUPT SERVICE ROUTINE PROG
       000200
       000062
002114 012737         MOV #101.,@#177560      ;SET READER ENABLE
       000145
       177560
                                                      ;AND INTERRUPT ENABLE


002122 000205         RTS R5


              ;
              ;SUBROUTINE GETS ACHARACTER FROM TTY KB
              ;
002124 005237 GETCHR: INC @#177560    ;RDR ENABLE
       177560
002130 005067         CLR GETFLG      ;FLAG=0INDICATES THAT
       001564
                                      ;CHARACTER IN BUFFER IS NOT READ
002134 005767 GEWAIT: TST GETFLG
       001560
002140 001775         BEQ GEWAIT      ;WAIT TILL BUFFER IS READ
002142 116700         MOVB RDRLOC,R0  ;RDRLOC CONTAINS CH. READ FROM BUFFER
       001550
002146 000205         RTS R5

              ;
              ;
              ;THIS SUBROUTINE PRINT S A STRING OF CHARACTERS POINTED
              ;TO BY R4 UNTILL A 0 IS ENCOUNTERED
              ;
002150 010046 MESS:   MOV R0,-(SP)
002152 112400 MLLOOP: MOVB (R4)+,R0   ;MOV THE BYTE POINTED TO AND INCREMENT T
002154 001403         BEQ MDDONE      ;IS BYTE EQUAL TO 0?
002156 004567         JSR R5,PUTCHR
       000006

                                      ;THE REST OF THE MESSAGE
002162 000773         BR MLLOOP
              ;
002164 012600 MDDONE: MOV (SF)+,R0
002166 000205         RTS R5
              ;
002170 105737 PUTCHR: TSTB @#177564   ;TELEPRINTER READY?
       177564
002174 100375         BPL PUTCHR


002176 110037         MOVB R0,@#177566        ;CHARACTER TO TELEPRINTER
       177566
002202 000205         RTS R5
              ;
```

```
                        PAGE    004

                  ;
                  ;
                  ;
                  ; THIS SUBROUTINE GETS A ;INE OF CHARACTERS FROM TTY
                  ; AND LEAVE THEM IN THE BUFFER
                  ;
002204 010046 LINE: MOV R0,-(SP)
002206 010146           MOV R1,-(SP)
002210 010246           MOV R2,-(SP)
002212 010346           MOV R3,-(SP)
002214 010446           MOV R4,-(SP)
                  ;
002216 012701 LENTER: MOV#BUFFER,R1    ;BUFFER POINTER
       002410
002222 012702           MOV #BUFEND,R2  ;BUFFER END POINTER
       002520
002226 010103           MOV R1,R3       ;BEGINNING OF BUFFER
002230 005004           CLR R4  ;RUBOUT FLAG
                  ;
002232 020102 LLOOP:CMP R1,R2 ;AT THE END?
002234 001450           BEQ TOOBIG
002236 004567           JSR R5,GETCHR   ;GET CHARACTER FROM TTY
       177662
002242 120027           CMPB R0,#177    ;RUBOUT?
       000177
002246 001525           BEQ RUBOUT
002250 120027           CMPB R0,#33     ;ESCAPE(CONTOL SHIFT K KEY)
       000033
002254 001450           BEQ DELETE
002256 120027           CMPB R0,#25     ;CONTROL U KEY?
       000025
002262 001445           BEQ DELETE
002264 005704           TST R4  ;WAS RUBOUT PREVIOUS INPUT?
002266 001407           BEQ LOK ;IF NOT BRANCH
002270 010046           MOV R0, -(SP)   ;IF SO SAVE CH FROM KB
002272 012700           MOV #57,R0      ;FILE SEPERATOR CHARACTER
       000057
002276 004567           JSR R5,PUTCHR
       177666
002302 005004           CLR R4
002304 012600           MOV(SP)+,R0     ;RESTORE CH FORM STACK
                  ;
002306 110021 LOK: MOVB R0,(R1)+        ;LOAD INTO BUFFER AND INCREMENT POINTER
002310 120027           CMPB R0,#15     ;CARRIAGE RETURN?
       000015
002314 001413           BEQ LDONE1      ;IF SO DONE
002316 004567           JSR R5,PUTCHR
       177646
002322 120027           CMPB R0,#54     ;COMMA?
       000054
002326 001341           BNE LLOOP       ;IF NOT BACK TO GET MORE CHARACTERS FROM
                  ;


002330 012604 LDONE2:MOV(SP)+,R4        ;RESTORE REG. CONTENTS FROM STACK
                                        ;BEFORE EXIT
002332 012603           MOV (SP)+,R3
002334 012602           MOV (SP)+,R2
```

```
                                PAGE    005
002336 012601           MOV(SP)+,R1
002340 012600           MOV (SP)+,R0
002342 000205           RTS R5
                ;
002344 012704 LDONE1: MOV #CRLF,R4      ;CR AND LF CHS FOR TELEPRINTER
       002405
002350 004567           JSR R5,MESS
       177574
002354 000765           BR LDONE2       ;TO EXIT
                ;
002356 012704 TOOBIG: MOV#LBIG,R4       ;REENTER ROUTINE TO SET UP BUFFER AGAIN
       002370
                                        ;AFTER PRINTING MESSAGE '?' ON PRINTER
002362 004567 TWOBIG: JSR R5,MESS
       177562
002366 000713           BR LENTER
                ;
002370    015 LBIG: .BYTE 15,12
002371    012
002372    077           .ASCII /?/
002373    015           .BYTE 15,12,0
002374    012
002375    000
                ;
002376 012704 DELETE: MOV #LDEL,R4      ;PRINT MESSAGE 'D'AND BRANCH
       002404
002402 000767           BR TWOBIG
                ;
002404    104 LDEL:   .ASCII /D/
002405    015 CRLF:.BYTE 15,12,0
002406    012
002407    000
       002410           .EVEN
       002520 BUFFER: .=.+110 ;BUFFER AREA
       002522 BUFEND: .=.+2
002522 020103 RUBOUT: CMP R1,R3         ;POINTER AT BEG. OF BUFFER
002524 001642           BEQ LLOOP
                                                 ;LOOP TO GET OTHER CH.
002526 005704           TST R4          ;CH IF THERE WAS A PREVIOUS RUBOUT
002530 001005           BNE DIRTY
002532 012700           MOV #57,R0
       000057
002536 004567           JSR R5,PUTCHR   ;PUNCH IT AND RESET FLAG
       177426
002542 005204            INC R4
002544 114100 DIRTY: MOVB-(R1),R0       ;DEC POINTER,UNLOAD CH IN BUFFER
002546 004567           JSR R5,PUTCHR
       177416
002552 000627           BR LLOOP        ;BACK TO LOOP
                ;
                ;
                ;ROUTINE TO ASSEMBLE A NUMERIC VALUE FROM TTY


                ;RETURNS WITH POSITIVE NUMBER IN BINARY IN R0
                ;ERROR MESSAGE "RETYPE" ON TTY FOR THE FOLLOWING:
                ;(1)A NON NUMERIC CH INCLUDING SIGN CHS  (2) NUMBER TYPED
                ;IN IS LARGER THAN 2^15-1. AFTER THE ERROR MESSAGE
```

```
                        PAGE    006

                   ;RETYPE THE NUMBER
                   ;
                   ;
002554 010146 GETNUM: MOV R1,-(SP)
002556 010246         MOV R2,-(SP)
002560 010446         MOV R4,-(SP)
002562 012701 GBACK:MOV#BUFFER,R1
       002410
002566 005002         CLR R2
002570 004567         JSR R5,LINE
       177410
002574 112100 GLOOP1:MOVB (R1)+,R0
002576 120027         CMPB R0,#15      ;CR?
       000015
002602 001425         BEQ GDONE1
002604 120027         CMPB R0,#54      ;COMMA?
       000054
002610 001422         BEQ GDONE1
002612 162700         SUB #60,R0
       000060
002616 100424         BMI GBAD         ;TO BINARY
002620 022700         CMP #12,R0
       000012
002624 003421         BLE GBAD         ;IF NOT
002626 006302         ASL R2
002630 102417         BVS GBAD
002632 010204         MOV R2,R4
002634 006302         ASL R2
002636 102414         BVS GBAD
002640 006302         ASL R2
002642 102412         BVS GBAD
002644 060402         ADD R4,R2        ;R2=R2*10
002646 102410         BVS GBAD
002650 060002         ADD R0,R2        ;R2=R2*10 +R0
002652 102406         BVS GBAD         ;OVERFLOW I.E. MAG OF NO IS GREATER THAN
002654 000747         BR GLOOP1        ;
002656 010200 GDONE1: MOV R2,R0
002660 012604         MOV (SP)+,R4     ;RESTORE
002662 012602         MOV (SP)+,R2     ;R4,R2,R1
002664 012601         MOV (SP)+,R1
002666 000205         RTS R5
002670 012704 GBAD:   MOV #GEVIL,R4
       002702
002674 004567         JSR R5,MESS
       177250
002700 000730         BR GBACK
002702    015 GEVIL:  .BYTE 15,12      ;CRLF
002703    012
002704    122         .ASCII /RETYPE/
002705    105
002706    124
002707    131


002710    120
002711    105
002712    015         .BYTE 15,12,0
002713    012
```

```
                      PAGE   007
002714   000
       002716         .EVEN

                ;OUTPUTS DATA ON TTY
                ;CALLING SEQUENCE:
                ;       JSR R5,ICABUF
                ;       .WORD N        ;NO. OF VARIABLES IN LIST
                ;       .WORD A1,A2.....,AN
                ;                      ;OUPUT LIST OF VARIABLES
                ;
                ;FORMAT OF OUTPUT:(/N(2X,I6,4X))
                ;
                ;
                ;
002716 010046 ICABUF: MOV R0,-(SP)
002720 010246         MOV R2,-(SP)
002722 010446         MOV R4,-(SP)
002724 012702         MOV#BUFFER,R2
       002410
002730 012567         MOV (R5)+,WORCNT          ;NO OF WORDS
       000046
002734 013500 ICALUP: MOV@(R5)+,R0     ;R0
002736 004567         JSR R5,ICA       ;CONVERTS BINARY TO ASCII,LOADS SIGN
       000042
                ;               PLUS FIVE DIGITS PLUS FOUR
                                ;SPACES INTO BUFFER
002742 005367         DEC WORCNT
       000034
002746 003372         BGT ICALUP       ;LOOP BACK IF ALL WORDS NOT DONE
002750 112722         MOVB #15.(R2)+
       000015
002754 112722         MOVB #12.(R2)+
       000012
002760 105012         CLRB (R2)        ;IF DONE LOAD CRLF AND 0
002762 012704         MOV #BUFFER,R4
       002410
002766 004567         JSR R5,MESS      ;PRINT THE NUMBER IN THE BUFFER
       177156
002772 012604         MOV (SP)+,R4
002774 012602         MOV (SP)+,R2
002776 012600         MOV (SP)+,R0
003000 000205         RTS R5
                ;
003002 000000 WORCNT: .WORD 0
                ;
                ;
                ;
                ;
                ;ICA SUBROUTINE
                ;CONVERTS BINARY INTEGER IN R0 TO ASCII CODE
                ;AT ADDRESS BUFFER. BUFFER CONTAINS LEADING SIGN BYTE
                ;FOLLOWED BY FIVE NUMERICAL DIGITS AND FOUR SPACE


                ;ASCII BYTES. BUFFER ADDREDD AVAILABLE IN R2
                ;
003004 010146 ICA:    MOV R1,-(SP)
003006 010346         MOV R3,-(SP)
```

```
                      PAGE   010

003010 010446         MOV R4,-(SP)
003012 012701         MOV #DWORD,R1
       003134
003016 005700         TST R0  ;CHECK SIGN
003020 100403         BMI ICA3
003022 112722         MOVB #53.,(R2)+  ;LOAD ASCII CH. FOR +
       000053
003026 000404         BR ICLOOP
003030 112722 ICA3: MOVB #55.,(R2)+    ;-ASCII CH
       000055
003034 005400         NEG R0
003036 102427         BVS ICAERR       ;NEGMAX
003040 005003 ICLOOP: CLR R3  ;SCALE FLAG
003042 011104         MOV(R1),R4       ;ELEMENT OF DECIMAL ARRAY
003044 001414         BEQ ICEND        ;IF EQ 0,DONE
003046 020004 ICA2: CMP R0,R4          ;R0<R4?
003050 002404         BLT ICA1         ; YES,GO TO NEXT ELEMENT
003052 005203         INC R3           ;INCREMENT       FACTOR
003054 061104         ADD (R1),R4      ;NO,ADD ARRAY ELEMEMT TO R4
003056 102401         BVS ICA1         ;OVERFLOW
003060 000772         BR ICA2          ;LOOP BACK
              ;
003062 062703 ICA1: ADD #60,R3         ;CONVERT SCALE TO ASCII
       000060
003066 110322         MOVB R3,(R2)+    ;LOAD SCALE ONTO BUFFER
003070 160400         SUB R4,R0        ;FORM REMAINDER
003072 062100         ADD (R1)+,R0     ;IN R0
003074 000761         BR ICLOOP
003076 012703 ICEND: MOV #020040,R3    ;TWO ASCII SPACE CHS.
       020040
003102 010322         MOV R3,(R2)+
003104 010322         MOV R3,(R2)+
003106 012604         MOV (SP)+,R4
003110 012603         MOV (SP)+,R3
003112 012601         MOV (SP)+,R1
003114 000205         RTS R5
003116 112722 ICAERR: MOVB #63.,(R2)+
       000063
003122 012722         MOV #031067,(R2)+
       031067
003126 012722         MOV #033070,(R2)+        ;LOAD -32768 IN BUFFER
       033070
003132 000761         BR ICEND
003134 023420 DWORD: .WORD 10000.,1000.,100.,10.,1.,0
003136 001750
003140 000144
003142 000012
003144 000001
003146 000000

                      ;
                      ;SUBROUTINE TO HANDLE INFUT FROM TTY
              ;CALLING SEQUENCE

              ;       JSR R5,INBUF
              ;       .WORD N ;NO.OF VARIABLES IN INPUT LIST
```

```
              ;                             ;N PAIRS OF WORDS FOLLOW
              ;                             ;FIRST WORD OF PAIR CONTAINS ADD
              ;                             ;VARIABLE MESSAGE TO TTY
              ;                             ;SECOND WORD THE VARIABLE ADDRES

              ;      .WORD AMESS,A
              ;      .WORD BMESS,B
              ;
              ;      .WORD NMESS,N
              ;                             ;PROGRAMME RETURNS HERE
              ;
              ;
003150 010046 INBUF: MOV R0,-(SP)
003152 010146        MOV R1,-(SP)
003154 010216        MOV R2,-(SP)
003156 010346        MOV R3,-(SP)
003160 010446        MOV R4,-(SP)
003162 012503        MOV (R5)+,R3      ;COUNT OF VARIABLES TO BE INPUT
003164 012700 INBU1: MOV #020040,R0    ;TWO ASCII SPACE CHS.
       020040
003170 004567        JSR R5,PUTCHR     ;TWO BLANK SPACES ONTO TTY
       176774
003174 012504        MOV (R5)+,R4      ;POINTER TO THE MESSAGE TO TTY
003176 004567        JSR R5,MESS       ;PRINT THE MESSAGE ON TTY
       176746
003202 004567        JSR R5,GETNUM     ;GET THE INPUT FROM TTY
       177346
003206 010035        MOV R0,@(R5)+     ;MOV THE INPUT TO THE VARIABLE ADDRESS
003210 005303        DEC R3            ;DECREMENT THE COUNT
003212 001364        BNE INBU1         ;BACK,IF ALL VARIABLES NOT INPUT
                     ;
003214 012604        MOV (SP)+,R4
003216 012603        MOV (SP)+,R3
003220 012602        MOV (SP)+,R2
003222 012601        MOV (SP)+,R1
003224 012600        MOV (SP)+,R0
003226 000205        RTS R5
              ;
              ;SUBROUTINE TO HANDLE INPUT FROM TTY
              ;FORMAT (NI-),- FOLLOWING I INDICATES
              ;THAT WORD IS INPUT IN I FORMAT AND COULD BE TERMINATED
              ;BY A CR OR COMMA
              ;
003230 010046 IBUFER: MOV R0,-(SP)
003232 010446        MOV R4,-(SP)
003234 012504        MOV (R5)+,R4      ;NO OF WORDS TO BE INPUT
003236 004567 IBUFBA: JSR R5,GETNUM
       177312
003242 010035        MOV R0,@(R5)+
003244 005304        DEC R4
003246 001373        BNE IBUFBA
003250 012604        MOV (SP)+,R4

003252 012600        MOV (SP)+,R0
003254 000205        RTS R5
              ;
```

```
               ;

               ;
               ;TTY INTERRUPT SERVICING ROUTINE
               ;
003256 113767 RDRINT: MOVB @#177562.RDRLOC     ;MOVE BYTE
       177562
       [illegible]0432
003264 042767         BIC #177600.RDRLOC       ;ASCII CODE
       177600
       000424
003272 126727         CMPB RDRLOC.#3  ;CONTROL C KEY INPUT?
       000420
       000003
003300 001403         BEQ RDR1        ;IF SO BRANCH
003302 005267         INC GETFLG
       000412

003306 000002         RTI             ;IF NOT RETURN TO THE POINT OF
                                      ;INTERRUPTION
003310 016646 RDR1:   MOV 2(SP),-(SP) ;SET UP PROGRAMME STATUS FO[illegible]
       000002
                                      ;EXECUT
003314 012746         MOV #EXECUT,-(SP)
       003322
003320 000002         RTI
               ;
               ;
               ;EXECUTIVE PROGRAMME
               ;ENTERED FROM TTY KB BY CONTROL C KEY INPUT.
               ;A VARIETY OF EXECUTIVE OR MONITOR FUNCTIONS COULD BE INCLUDED H
               ;
003322 016746 EXECUT: MOV BUFFER,-(SP)
       177062
003326 016746         MOV BUFFER+2,-(SP)       ;SAVE PREVIOUS CONTENTS OF BUFFE
       177060
                                               ;ONLY FIRST TWO WORDS SAVED
003332 010046         MOV R0,-(SP)
003334 010146         MOV R1,-(SP)
003336 010246         MOV R2,-(SP)
003340 010346         MOV R3,-(SP)

003342 010446         MOV R4,-(SP)
003344 010546         MOV R5,-(SP)


003346 112700         MOVB #'..R0
       000056
003352 004567         JSR R5,PUTCHR   ;PRINT '.' ON TTY
       176612
003356 004567 EXELUP: JSR R5.LINE     ;GET A LINE OF CHS. FROM KB
       176622


003362 016700         MOV BUFFER,R0   ;ADDRESS OF FIRST WORD OF INPUT CHS
       177022
                                      ;R0 CONTAINS FIRST TWO BYTES
003366 020027         CMP R0,#"CO     ;=CO?
       047503
```

AD-A072 822 TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MA F/G 1/5
THE DEVELOPMENT OF A SIGNAL DATA CONVERTER FOR AN AIRPORT VISIB--ETC(U)
AUG 75 H C INGRAO, M YAFFEE, M F CARTWRIGHT

UNCLASSIFIED TSC-FAA-74-20 FAA-RD-75-65 NL

3 OF 3
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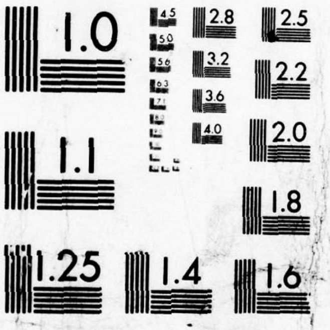

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
003372 001424         BEQ EXECON
003374 020027         CMP R0,#"RE      ;=RE?
       042522
003400 001436         BEQ EXERES
003402 020027         CMP R0,#"AR      ;=AR?
       051101
003406 001435         BEQ EXEART
003410 020027         CMP R0,#"IO      ;=IO?
       047511
003414 001434         BEQ EXEIOT
003416 020027         CMP R0,#"TI      ;=TI?
       044524
003422 001433         BEQ EXETIM
003424 020027         CMP R0,#"DA      ;=DA?
       040504
003430 001472         BEQ EXEDAY
003432 112700 EXEOUT: MOVB #'?,R0
       000077
003436 004567         JSR R5,PUTCHR    ;IF NONE OF ABOVE PRINT '?' ON TTY
       176526
003442 000745         BR EXELUP        ;AND BACK TO GET CORRECT COMMAND
              ;
003444 012605 EXECON: MOV (SP)+,R5
003446 012604         MOV (SP)+,R4
003450 012603         MOV (SP)+,R3
003452 012602         MOV (SP)+,R2
003454 012601         MOV (SP)+,R1


003456 012600         MOV (SP)+,R0
003460 012667         MOV (SP)+,BUFFER+2
       176726
003464 012667         MOV (SP)+,BUFFER          ;RESTORE BUFFER CONTENTS
       176720
003470 005067         CLR GETFLG       ;SET THE GETCHR ROUTINE FLAG=0
       000224

003474 000002         RTI
              ;
003476 004567'EXERES: JSR R5,VISIB
       000000
              ;
003502 004567'EXEART: JSR R5,ARTEST
       000000
              ;
003506 004567 EXEIOT: JSR R5,IOTEST
       176266
              ;
003512 126727 EXETIM: CMPB BUFFER+2,#15         ;CR?
       176674
       000015
003520 001427         BEQ EXETI1


003522 126727         CMPB BUFFER+2,#54         ;COMMA?
       176664
       000054
003530 001340         BNE EXEOUT       ;IF 'TI' IS NOT TERMINATED BY CR OR
```

```
                      PAGE    014
                                      ;COMMA BACK TO GET CORRECT COMMAND
003532 004567         JSR R5,IBUFER
       177472
003536 000003         .WORD 3
003540 000000'        .WORD THR,TMIN,TSEC
003542 000000'
003544 000000'
003546 026727'        CMP THR,#23.    ;THR>23?
       000000
       000027
003554 003326         BGT EXEOUT
003556 026727'        CMP TMIN,#59.   ;TMIN>59?
       000000
       000073
003564 003322         BGT EXEOUT
003566 026727'        CMP TSEC,#59.   ;SEC>59?
       000000
       000073
003574 003316         BGT EXEOUT
                                      ;IF TIME INPUT IS INVALID
                                      ;'?' IS PRINTED ON TTY
                                      ;INPUT COMMAND STRING AGAIN
003576 000722         BR EXECON

              ;
003600 004567 EXETI1: JSR R5,ICABUF
       177112
003604 000003         .WORD 3
003606 000000'        .WORD THR,TMIN,TSEC
003610 000000'
003612 000000'


003614 000713         BR EXECON
              ;
003616 126727 EXEDAY: CMPB BUFFER+2,#15       ;CR?
       176570
       000015
003624 001425         BEQ EXEDA1
003626 126727         CMPB BUFFER+2,#54       ;COMMA?
       176560
       000054
003634 001276         BNE EXEOUT

003636 004567         JSR R5,IBUFER   ;ACCEPT DAY,MONTH AND YEAR FROM KB
       177366
003642 000003         .WORD 3
003644 000000'        .WORD TDAY,TMON,TYEAR
003646 000000'
003650 000000'
003652 026727'        CMP TMON,#12.   ;TMON>12?


       000000
       000014
003660 003264         BGT EXEOUT
```

```
                      PAGE    015
003662 004567         JSR R5,MONDET
       000034
003666 026767'        CMP TDAY,MONDAY ;TDAY.GE.MAXIMUM DAYS
       000000
       000000
                                      ;INA MONTH+1?
003674 002256         BGE EXEOUT

                                      ;IF DATE INPUT IS ILLEGAL
                                      ;'?' IS PRINTED ON TTY
                                      ;AND FRESH COMMAND STRING CAN BE INPUT


003676 000662         BR EXECON       ;CONTINUE WITH THE PROGRAMME
003700 004567 EXEDA1: JSR R5,ICABUF
       177012
003704 000003         .WORD 3
003706 000000'        .WORD TDAY,TMON,TYEAR   ;PRINT DAY,MON,YEAR ON TTY
003710 000000'
003712 000000'
003714 000653         BR EXECON
              ;
003716 000000 RDRLOC: .WORD 0
003720 000000 GETFLG: .WORD 0


              ;FOLLOWING ROUTINE DETERMINES DAYS IN A MONTH
              ;LEAP YEAR ALSO ACCOUNTED FOR
              ;MONDAY=MAXIMUM NO OF DAYS IN THE MONTH+1

              ;
003722 010046 MONDET:MOV R0,-(SP)
003724 016700'        MOV TMON,R0
       000000
003730 020027         CMP R0,#7       ;COMPARE TO JULY?
       000007
003734 003016         BGT EXE2        ;BRANCH IF GREATER
003736 020027         CMP R0,#2       ;FEB?
       000002

003742 001416         BEQ EXE3
003744 006200 EXE7:   ASR R0  ;DIVIDE BY 2
003746 103404         BCS EXE4        ;JUMP IF ODD MONTH
003750 012767'        MOV #31.,MONDAY ;=30+1
       000037
       000000
003756 000403         BR EXE5
003760 012767'EXE4:   MOV #32.,MONDAY ;=31+1
       000040
       000000
003766 012600 EXE5:   MOV (SP)+,R0
003770 000205         RTS R5


              ;
003772 162700 EXE2:   SUB#7,R0        ;FOR MONTHS STARTING WITH AUGUST
       000007
003776 000762         BR EXE7
```

```
                  ;FOR FEBRUARY
004000 016700'EXE3:     MOV TYEAR,R0
       000000
004004 006200           ASR R0  ;DIVIDE BY 2
004006 103406           BCS EXE6        ;CANNOT DIVIDE BY 2
004010 006200           ASR R0  ;FURTHER DIVIDE BY 2
004012 103404           BCS EXE6        ;CANNOT DIVIDE
004014 012767'          MOV #30.,MONDAY ;=29+1
       000036
       000000
004022 000761           BR EXE5
004024 012767'EXE6:     MOV #29.,MONDAY ;=28+1
       000035
       000000
004032 000755           BR EXE5
                  ;



                  ;
                  ;
                  ;

       002000 .END IOTEST
```

```
000000 ERRORS
```

```
              ;
              ;ARITHMETIC PACKAGE
              ;
              ;SUBROUTINES
              ;      ARTEST: ARTH.PACKAGE SOFTWARE TEST ROUTINE
              ;      MULT:   MULTIPLY ROUTINE
              ;      DIV:    DIVIDE ROUTINE
              ;      FMULT:  SPECIAL MULTIPLY ROUTINE
              ;      FDIV:   SPECIAL DIVIDE ROUTINE
              ;      LOG:    LOGARITHM ROUTINE, BASE 10.
              ;      NORMD:  DOUBLE PRECISION NORMALIZATION ROUTINE
              ;      SALOG:  SUPPLIES SCALED LOGARITHM.
              ;      RSHIFT: RIGHT SHIFT ROUTINE
              ;      LSHIFT: LEFT SHIFT ROUTINE
              ;      NORM:   NORMALIZATION ROUTINE
              ;
              ;
       000000 R0=%0
       000001 R1=%1
       000002 R2=%2
       000003 R3=%3
       000004 R4=%4
       000005 R5=%5
       000006 SP=%6
       000007 PC=%7
              .TITLE ARTEST
       000000 .ASECT
              .GLOBL INBUF, MESS,ICABUF,INIT,GETNUM,ARTEST


       004400 .=4400
              .GLOBL LSHIFT,SCALE ,RSHIFT,DIV,MULT,LOG,SCALOG,NORM,FMULT,FDIV



              ;MULTIPLY ROUTINE
              ; SUPPLIES DOUBLE PRECISION INTEGER PRODUCTIN  (R0,R1)
              ; WITH SIGNIFICANT PRODUCT IN R1 AND OVERFLOW IN R0.
              ;MULTIPLICAND AND MULTIPLIER IN R0 AND R2
              ;
              ;
              ;
004400 005001 MULT: CLR R1      ;COUNTER
004402 010446         MOV R4,-(SP)
004404 005004         CLR R4  ;SIGN
004406 005700         TST R0  ;MULTIPLICAND
004410 001437         BEQ MULZER       ;ZERO PRODUCT
004412 100003         BPL MULT1        ;JUMP IF +
004414 005204         INC R4  ;NOTE -
004416 005400         NEG R0
004420 102436         BVS MULERR
              ;


004422 005702 MULT1: TST R2
004424 001431         BEQ MULZER
```

```
                        PAGE    001
004426 100003           BPL MULT2       ;JUMP IF -
004430 005204           INC R4  ; SET PRODUCT SIGN
004432 005402           NEG R2
004434 102430           BVS MULERR
                ;
004436 010346 MULT2: MOV R3,-(SP)
004440 012703           MOV #-16.,R3    ;SET CO"NTER
       177760
                ;
004444 006301 MLOOP:    ASL R1
004446 006100           ROL R0  ;DOUBLE PRECISION LEFT SHIFT
004450 103002           BCC NOADD       ; MOST SIG BIT GOVERNS ADD
004452 060201           ADD R2,R1       ;IF SET ADD MULT.
004454 005500           ADC R0  ;KEEP 32 BIT PRODUCT
                ;
004456 005203 NOADD:INC R3      ;DONE?
004460 001371           BNE MLOOP       ; IF NOT CONTINUE
004462 012603           MOV (SP)+,R3
004464 006004           ROR R4  ;GET PRODUCT SIGN
004466 103401           BCS MULOUT      ;JUMP IF -
004470 000405           BR MULT3
                        ;
004472 005100 MULOUT: COM R0
004474 005101           COM R1
004476 062701           ADD #1,R1
       000001
004502 005500           ADC R0
004504 012604 MULT3: MOV (SP)+,R4
004506 000205           RTS R5
                ;

                ;
004510 005000 MULZER: CLR R0    ;ZERO PRODUCT
004512 005001           CLR R1
004514 000773           BR MULT3
                ;
004516 012704 MULERR: MOV#MULMES,R4
       004530
004522 004567'          JSR R5,MESS
       000000
004526 000766           BR MULT3
                ;
004530    015 MULMES: .BYTE 15,12
004531    012
004532    116           .ASCII /NEGMAX,MUL/
004533    105
004534    107
004535    115
004536    101
004537    130
004540    054
004541    115


004542    125
004543    114
004544    015           .BYTE 15,12,0
004545    012
```

```
004546     003
       004550        .EVEN
              ;
              ;
              ;DIVIDE ROUTINE
              ;DOUBLE PRECISION DIVIDEND REQUIRED
              ;(R0,R1) CONTAINS DOUBLE PRECISION DIVIDED
              ;R2 DIVIDER
              ;QUOTIENT IN R1
              ;
              ;
004550 010346 DIV: MOV R3,-(SP)
004552 005003        CLR R3  ;SIGN
004554 005702        TST R2  ;DENOMINATOR
004556 001447        BEQ DIVERR       ;CANNOT DIVIDE BY ZERO
004560 100002        BPL DIV1         ;JUMP IF +
004562 005203        INC R3  ;NOTE-
004564 005402        NEG R2
              ;
004566 005700 DIV1:  TST R0  ;CHECK NUMERATOR
004570 001436        BEQ DIV5
004572 100006        BPL DIV2         ;JUMP IF +
004574 005203        INC R3  ;SET RESULT SIGN
004576 005100        COM R0
004600 005101        COM R1
004602 062701        ADD #1,R1
       000001
004606 005500        ADC R0
              ;
004610 020200 DIV2:  CMP R2,R0
004612 103437        BLO DIVER2
004614 010446        MOV R4,-(SP)

004616 012704        MOV #16.,R4      ;SET FOR 16 ITERATIONS
       000020
              ;
004622 006301 DIV3: ASL R1
004624 006100        ROL R0  ;DOUBLE PRECISION SHIFT
004626 001405        BEQ DIVLUP       ;JUMP IF R0=0
004630 005201        INC R1  ;ASSUME IT WILLGO.INSERT QUOTINT BIT
004632 160200        SUB R2,R0        ;TRIAL STEP
004634 103002        BHIS DIVLUP      ;OK
004636 060200        ADD R2,R0        ;DIVIDEND NOT BIG ENOUGH YET
004640 005301        DEC R1  ;TAKE OUT QUOTIENT BIT
004642 005304 DIVLUP:DEC R4
004644 003366        BGT DIV3         ;GO AGAIN
004646 012604 DIV6:  MOV (SP)+,R4
004650 005401        NEG R1  ;TEST FOR NEGMAX
004652 006203        ASR R3  ;GET RESULT SIGN
004654 103402        BCS DIV4         ;JUMP IF NEG
004656 005401        NEG R1  ;ANSWER IS +
004660 102406        BVS DIVERR       ; JUMP IF ANSWER IS NEGMAX


004662 012603 DIV4: MOV(SP)+,R3
004664 000205        RTS R5  ;QUOTIENT IN R1
              ;
004666 005701 DIV5:  TST R1
```

```
                      PAGE    003
004670 001347         BNE DIV2
004672 005001 DIVZER: CLR R1   ; RESULT IS ZERO
004674 000772         BR DIV4
              ;
004676 010446 DIVERR: MOV R4,-(SP)
004700 012704         MOV #DIVMES,R4
       004734
004704 004567'        JSR R5,MESS
       000000
004710 012604         MOV (SP)+,R4

004712 010446 DIVER2: MOV R4,-(SP)
004714 012704         MOV #DIMES2,R4
       004747
004720 004567'        JSR R5,MESS
       000000
004724 012701         MOV #070000,R1   ;SET MAG OF QUOTIENT=28672.
       070000
004730 000746         BR DIV6
004732 000753         BR DIV4
              ;
              ;
004734    015 DIVMES: .BYTE 15,12
004735    012
004736    104         .ASCII /DIV BY 0./
004737    111
004740    126
004741    040
004742    102
004743    131
004744    040
004745    060
004746    054
004747    105 DIMES2: .ASCII /ERR.DIV/
004750    122
004751    122
004752    054
004753    104
004754    111
004755    126
004756    015         .BYTE 15,12,0
004757    012
004760    000
       004762         .EVEN
              ;
              ;
              ;DIVIDE ROUTINE --FIXED POINT ARITHMETIC
              ;NUMERATOR IN R0
              ;DENOMINATOR IN R2
              ; QUOTIENT IN R1
              ;
              ;


004762 005001 FDIV: CLR R1
004764 006200         ASR R0
004766 006001         ROR R1   ;SET UP DIVIDEND FOR INTEGER DIV ROUTINE
004770 004567         JSR R5,DIV      ;CALL INT\GER DIVIDE ROUTINE
       177554
```

```
                      PAGE    004
004774 000205         RTS R5
              ;
              ;
              ;MULTIPLY ROUTINE--FIXED POINT ARITHMETIC
              ;MULTIPLICAND IN R0
              ;MULTIPLIER IN R2
              ;
              ;
004776 004567 FMULT:  JSR R5,MULT
       177376
005002 006301         ASL R1
005004 006100         ROL R0
005006 000205         RTS R5
              ;
              ;
              ;
              ;
              ;
              ;LOGARITHM SUBROUTINE
              ;SUPPLIES LOGARITHM TO BASE 10 OF INTEGER NUMBER
              ;INTEGER (I) AVAILABLE IN R0
              ;PROGRAMME RETURNS WITH LOG10(I) IN
              ;(R0,R1) WITH SIGNIFICANT PART IN R0
              ;ASSOCIATED SCALE FACTOR IN R2
              ;
              ;CONSTANTS
       026501         CL0=11585.
       110322         CL1=-28462.
       155364         CL3=-9484.
       164354         CL5=-5908.
       154570         L102=-9864.
              ;
005010 010346 LOG:    MOV R3,-(SP)
005012 010446         MOV R4,-(SP)
005014 005700         TST R0
005016 003502         BLE LOGERR     ;BRANCH IF LESS THAN OR EQUAL TO ZERO
005020 012701         MOV #15.,R1    ;SCALE FACTOR OF ARG I
       000017
005024 004567         JSR R5,NORM    ;NORMALIZE ARG
       000426
005030 010146         MOV R1,-(SP)   ;PUSH SCALE AT 15
005032 010046         MOV R0,-(SP)   ;STORE ARG AT 0
005034 006200         ASR R0  ;ARG AT 1
005036 062700         ADD #CL0,R0    ;ARG+1/SQRT2 AT 1
       026501
005042 010002         MOV R0,R2
005044 162600         SUB (SP)+,R0   ;-(ARG-1/SQRT2)AT 1
005046 004567         JSR R5,FDIV
       177710
005052 010146         MOV R1,-(SP)   ;Z AT 0


005054 010100         MOV R1,R0
005056 010102         MOV R1,R2
005060 004567         JSR R5,FMULT   ;Z2 AT J
       177712
```

```
005064 010046           MOV R0,-(SP)      ;STORE Z2
005066 012702           MOV #CL5,R2
       164354
005072 004567           JSR R5,FMULT      ;C5*Z2 AT 0
       177700
005076 062700           ADD #CL3,R0       ;C3+C5*Z2 AT 0
       155364
005102 012602           MOV (SP)+,R2      ;Z2 AT 0
005104 004567           JSR R5,FMULT      ;R0=Z2*(C3+C5*Z2) AT 0
       177666
005110 062700           ADD #CL1,R0       ;R0=C1+Z2*(C3+C5*Z2)AT 0
       110322
005114 012602           MOV (SP)+,R2      ;Z AT 0
005116 004567           JSR R5,FMULT      ;R0=Z*(C1+Z2*(C3+C5*Z2))
       177654
005122 012701           MOV #L102,R1      ;-L10(2) AT 0
       154570
005126 006201           ASR R1            ;DIVIDE BY 2
005130 060001           ADD R0,R1         ;R1=-LOG10(2)/2+Z*(C1+Z2*(C3+C5*Z2))
                                          ;R1=LOG10(FACTION)
                        ;
005132 012600           MOV (SP)+,R0      ;SCALE AT 15
005134 010146           MOV R1,-(SP)      ;L10(FR) AT 0
005136 000300           SWAB R0           ;EIGHT LEFT SHIFTS
005140 006300           ASL R0
005142 006300           ASL R0
005144 006300           ASL R0            ;THREE MORE SHIFTS, ELEVEN IN ALL
                                          ;SCALE AT 4
005146 012702           MOV #L102,R2      ;-L10(2) AT 0
       154570
005152 005402           NEG R2            ;L10(2) AT 0
005154 004567           JSR R5,FMULT
       177616
005160 005003           CLR R3            ;SET UP LOG10(FR) AT0 IN (R2,R3) IN DBL.
005162 012602           MOV (SP)+,R2
005164 012704           MOV #4,R4         ;COUNTER FOR SHIFTS
       000004
005170 006202 LOG1: ASR R2     ;LOW ORDER BIT TO C
005172 006003           ROR R3            ;C TO HIGH ORDER BIT OF R3
005174 005304           DEC R4
005176 001374           BNE LOG1          ;CONTINUE,IF NOT ZERO
                                          ;(R2,R3) CONTAINS LOG10(FR) AT 0
005200 060301           ADD R3,R1         ;L10(I)=L10(FR)+L10(EXPONENT) AT $
005202 005500           ADC R0            ;L10(I) IS IN (R0,R1) AT $
005204 060200           ADD R2,R0

005206 012702           MOV #4,R2         ;SCALE=4
       000004
005212 004567           JSR R5,NORMD      ;NORMALIZATION
       000052
                                          ;L10(I) IN(R0,R1) WITH SCALE FACTOR (R2)


005216 012604 LOG2: MOV (SP)+,R4
005220 012603           MOV (SP)+,R3

005222 000205           RTS R5
```

```
                         ;
005224 005000 LOGERR: CLR R0
005226 005001         CLR R1
005230 012704         MOV #LOGMES,R4
       005242
005234 004567'        JSR R5,MESS
       000000
005240 000766         BR LOG2
005242    015 LOGMES: .BYTE 15,12
005243    012
005244    132         .ASCII /ZERO RETURNED,LOG/
005245    105
005246    122
005247    117
005250    040
005251    122
005252    105
005253    124
005254    125
005255    122 .
005256    116
005257    105
005260    104
005261    054
005262    114
005263    117
005264    107
005265    015         .BYTE 15,12,0
005266    012
005267    000
       005270         .EVEN
              ;
              ;
              ;DOUBLE PRECISION NORMALIZATION ROUTINE
              ;FOR LOG ROUTINE ONLY
              ;(R0,R1) CONTAINS DOUBLE PRECION NUMBER
              ;(R2) CONTAINS SCALE OF THE NUMBER
              ;
005270 005302 NORMD:  DEC R2  ;SCALE
005272 006301         ASL R1
005274 006100         ROL R0  ;DOUBLE PRECION SHIFT
005276 001405         BEQ NORFIN      ;OPERATION COMPLETE IF R0 IS 0
005300 102373         BVC NORMD       ;CONTINUE IF SIGN DID NOT CHANGE
005302 006000         ROR R0          ;RESTORE SIGN
005304 006001         ROR R1          ;AND THE NUMBER
005306 005202         INC R2          ;AND THE SCALE
005310 000406         BR NORXIT       ;NORMALIZATION COMPLETE
005312 006000 NORFIN: ROR R0  ;RESTORE SIGN:000000 OR 100000
005314 006001         ROR R1
005316 006200         ASR R0
005320 006001         ROR R1          ;AND REPLICATE IT:000000 OR 140000
005322 005202         INC R2


005324 005202         INC R2          ;AND RESTORE THE SCALE
005326 000205 NORXIT: RTS R5
```

```
              ;
              ;SCALING ROUTINE FOR LOGARITHM ROUTINE
              ;R0 CONTAINS INTEGER I
              ;(R0,R1) ON RETURN FROM LOG ROUTINE CONTAINS LOG(I)*2**11
              ;SCALING NEEDED IS LOG(I)*2**SCALE
              ;ASSUMES SCALE<11
              ;LOG(I)*2**SCALE AVAILABLE IN R0
              ;
005330 010146 SCALOG: MOV R1,-(SP)
005332 010246         MOV R2,-(SP)
005334 004567         JSR R5,LOG      ;LOG ROUTINE
       177450
005340 012701         MOV#15.,R1
       000017

005344 160201         SUB R2,R1       ;SCALE OF NO IN (R0,R1) FROM LOG
005346 166701'        SUB SCALE,R1    ;
       000000
005352 001403         BEQ SCAXIT
005354 100405         BMI SCAL01

                                      ;WE NEED (R2-SCALE) RIGHT SHIFTS ON R0


005356 004567         JSR R5,RSHIFT   ;PERFORMS (R1) RIGHT SHIFTS ON R0
       000014
005362 012602 SCAXIT: MOV (SP)+,R2
005364 012601         MOV (SP)+,R1

005366 000205         RTS R5
              ;
005370 004567 SCAL01: JSR R5,LSHIFT
       000012
005374 000772         BR SCAXIT
              ;
              ;
              ;RIGHT SHIFT ROUTINE


              ;PERFORMS (R1) RIGHT SHIFTS ON R0
              ;(R1) SHOULD BE GREATER THAN ZERO


005376 006200 RSHIFT: ASR R0  ;SHIFT RIGHT

005400 005301                 DEC R1  ;DECREMENT COUNT
005402 001375                 BNE RSHIFT      ;LOOP BACK IF NOT FINISHED
005404 000205                 RTS R5
              ;
              ;LEFT SHIFT ROUTINE
              ;PERFORMS (R1) LEFT SHIFTS ON R0


              ;R1 SHOULD BE GREATER THAN 0
005406 006300 LSHIFT: ASL R0  ;SHIFT LEFT
005410 102403         BVS LSHERR
```

```
                        PAGE    010

005412 005301           DEC R1  ;DECREMENT COUNT
005414 001374           BNE LSHIFT      ;LOOP BACK IF NOT FINISHED
005416 000205           RTS R5
005420 006000 LSHERR:   ROR R0          ;CRUDE ATTEMPT IN HOPE SYSTEM MAY RECOVE
005422 010446           MOV R4,-(SP)
005424 012704           MOV #LSHMES,R4
       005440
005430 004567'          JSR R5,MESS
       000000

005434 012604           MOV (SP)+,R4
005436 000205           RTS R5
005440    015 LSHMES:   .BYTE 15,12
005441    012
005442    117           .ASCII /OV.FL;ASL/
005443    126
005444    056
005445    106
005446    114
005447    073
005450    101
005451    123
005452    114
005453    015           .BYTE 15,12,0
005454    012
005455    000


              ;
              ;
              ;
              :
              :NORMALIZATION ROUTINE
              :CALL:
              :         JSR R5,NORM
                        ;R0 CONTAINS THE FRACTION TO BE NORMALIZED
                        ;R1 THE SCALE FACTOR OF NUMBER IN R0
                        ;ON RETURN--R0 CONTAINS NORMALIZED FACTION
                        ;AND R1 THE ASSOCIATED SCALE FACTOR
              ;
              ;
005455 005301 NORM:     DEC R1  :DECREMENT SCALE
005460 006300           ASL R0  :SHIFT 0S INTO LOWER BIT
005462 001404           BEQ NFIN        :IF RESULT IS 0,OPERATION IS COMPLETE
005464 102374           BVC NORM        :IF SIGN DID NOT CHANGE CONTINUE
005466 006000           ROR R0          ;RESTORE SIGN
005470 005201           INC R1          :AND SCALE
005472 000404           BR NDONE        ;NORMALIZATION COMPLETE
005474 006000 NFIN:     ROR R0  ;RESTORE SIGN:000000 OR 100000
005476 006200           ASR R0          ;AND REPLICATE IT:000000 OR 140000
005500 005201           INC R1          :INCREMENT SCALE
005502 005201           INC R1          :INCREMENT SCALE


005504 000205 NDONE:    RTS R5
              ;
              ;
              ;ARITHMETIC PACKAGE TEST ROUTINE
```

```
                                 PAGE    011

                             ;NEEDS TTY IO PACKAGE
                             ;ACCEPTS + INTEGER I FROM TTY AND
                             ;PRINTS LOG10(I)*2**SCALE WHERE
                             ;REQUIRED VALUE OF SCALE HAS TO BE SET
                             ;IN THE APPROPRIATE VARIABLE ADDRESS

                             ;
        005506 004567'ARTEST: JSR R5,INIT'
               000000

        005512 004567'ARBACK: JSR R5,INBUF
               000000
        005516 000001         .WORD 1
        005520 005554         .WORD AWORD,AR1
        005522 005560
        005524 016700         MOV AR1,R0
               000030


        005530 004567 .       JSR R5,SCALOG
               177574
        005534 010067         MOV R0,DR1
               000022
        005540 004567'        JSR R5,ICABUF
               000000
        005544 000002         .WORD 2,AR1,DR1
        005546 005560
        005550 005562
        005552 000757         BR ARBACK
        005554    111 AWORD:  .ASCII /I=/
        005555    075
        005556    000         .BYTE 0
               005560         .EVEN
        005560 000000 AR1:    .WORD 0

        005562 000000 DR1:    .WORD 0

                             ;

                             ;
               005506         .END ARTEST




                                 PAGE    012

       000000 ERRORS
```

```
ARBACK   005512        ARTEST   005506 G     AR1      005560
AWORD    005554        CL0    = 026501       CL1    = 110322
CL3    = 155364        CL5    = 164354       DIMES2   004747
DIV      004550 G      DIVERR   004676       DIVER2   004712
DIVLUP   004642        DIVMES   004734       DIVZER   004672
DIV1     004566        DIV2     004610       DIV3     004622
DIV4     004662        DIV5     004666       DIV6     004646
DR1      005562        FDIV     004752 G     FMULT    004776 G
GETNUM = ****** G      ICABUF = ****** G     INBUF  = ****** G
INIT   = ****** G      LOG      005010 G     LOGERR   005224
LOGMES   005242        LOG1     005170       LOG2     005216
LSHERR   005420        LSHIFT   005406 G     LSHMES   005440
L102   = 154570        MESS   = ****** G     MLOOP    004444
MULERR   004516        MULMES   004530       MULOUT   004472
MULT     004400 G      MULT1    004422       MULT2    004436
MULT3    004504        MULZER   004510       NDONE    005504
NFIN     005 74        NOADD    004456       NORFIN   005312
NORM     005456 G      NORMD    005270       NORXIT   005326
PC      =%000007       RSHIFT   005376 G     R0      =%000000
R1      =%000001       R2      =%000002      R3      =%000003
R4      =%000004       R5      =%000005      SCALE  = ****** G
SCALOG   005330 G      SCALO1   005370       SCAXIT   005362
SP      =%000006              = 005564
```

```
ARTEST = ****** G    BUFEND   002520      BUFFER   002410
CRLF     002405      DELETE   002375      DIRTY    002544
DWORD    003134      EXEART   003502      EXECON   003444
EXECUT   003322      EXEDAY   003616      EXEDA1   003700
EXEIOT   003506      EXELUP   003356      EXEOUT   003432
EXERES   003476      EXETIM   003512      EXETI1   003600
EXE2     003772      EXE3     004000      EXE4     003760
EXE5     003766      EXE6     004024      EXE7     003744
GBACK    002562      GBAD     002670      GDONE1   002656
GETCHR   002124 G    GETFLG   003720      GETNUM   002554 G
GEVIL    002702      GEWAIT   002134      GLOOP1   002574
IBUFBA   003236      IBUFER   003230      ICA      003004 G
ICABUF   002716 G    ICAERR   003116      ICALUP   002734
ICA1     003062      ICA2     003046      ICA3     003030
ICEND    003076      ICLOOP   003040      INBUF    003150 G
INBU1    003164      INIT     002052 G    IOTEST   002000 G
LBIG     002370      LDEL     002404      LDONE1   002344
LDONE2   002330      LENTER   002216      LINE     002204 G
LKSERV = ****** G    LLOOP    002232      LOK      002306
MAINBA   002004      MAINBU   002044      MAINME   002032
MDDONE   002164      MESS     002150 G    MLLOOP   002152
MONDAY = ****** G    MONDET   003722 G    PC      =%000007
PUTCHR   002170 G    RDRINT   003256      RDRLOC   003716
RDR1     003310      RUBOUT   002522      R0      =%000000
R1      =%000001     R2      =%000002     R3      =%000003
R4      =%000004     R5      =%000005     SP      =%000006
TDAY   = ****** G    THR    = ****** G    TMIN   = ****** G
TMON   = ****** G    TOOBIG   002356      TSEC   = ****** G
TWOBIG   002362      TYEAR  = ****** G    VISIB  = ****** G
WORCNT   003002      .      = 004034
```

```
BALEPS  010562          BASE    010502          BGILIN  010214
BUFFIC  010470          CAIB    010572          CAIK    010574
CALBAC  005642          CALC    005600          CTRFLG  010522
DIAGNO  010614          DISERR  010462          DISPLA  010332
DISPL1  010374          DISPL2  010436          DISPL3  010454
DISPL4  010354          DIV     = ****** G      DPRNT1  006376
DPRNT2  006416          DPR1    006414          DPR2    006444
DUM     010566          ET      010506          ETTBL   010270
FSTIME  010520          GETCHR  = ****** G      GETNUM  = ****** G
ICA     = ****** G      ICABUF  = ****** G      INBUF   = ****** G
INFLAG  010524          INIT    = ****** G      INMODE  010512
INPUT   007214          INTFAC  010030          INTSTY  010504
INTTBL  010260          INTTY   007230          IOD1    010126
IOD10   010200          IOD11   010236          IOD12   010246
IOD3    010072          IOD4    010064          IOD7    010134
IOD9    010170          ITCRLF  006372          ITER    005750
ITERER  006342          ITEREX  006306          ITERLU  005762
ITERMA  = 000012        ITERME  006360          ITER1   006212
ITER10  006144          ITER11  006114          ITER2   006224
ITER3   006234          ITER4   006252          ITER5   006260
ITER6   006340.         ITER8   006136          ITER9   006140
ITIV    010570          ITMESS  006446          ITRANS  010554
LEPS    010624          LKSERV  006676 G        LK1     006726
LK2     006744          LK3     006762          LK4     007136
LK5     007164          LK7     007200          LK8     007116
LK9     007126          LOGNBM  010576          LSHIFT  = ****** G
L5280   010622          MAGSCA  010620          MESS    = ****** G
MEXIT   010626          MODNR   010630          MONDAY  010546 G
MONDET  = ****** G      MULT    = ****** G      MWORD1  007706
MWORD2  007712          MWORD3  007720          MWORD4  007730
MWORD5  007734          MWORD6  007274          MWORD7  007304
MWORD8  007310          MWORD9  007320          NCOUNT  010516
NINPUT  = 000005        NOITER  010556          NPUL    010606
NTRANS  = 000002        NTRDBL  = 000004        NWORD1  007744
NWORD2  007754          NWORD3  007764          OUTATC  006532
OUTA1   006544          OUTMES  006602          OUTPUT  006504
OUTREC  006546          OUTSTR  010306          PARMES  007656
PBACK   007624          PC     =%000007         PRATE   010510
PUTCHR  = ****** G      RINTIN  010152          RSELEC  010526
RSHIFT  = ****** G      R0     =%000000         R1     =%000001
R2     =%000002         R3     =%000003         R4     =%000004
R5     =%000005         SCALE   010616 G        SCALOG  = ****** G
SP     =%000006         SPABAC  010002          SPACE   007774
SFCRLF  010024          STROBE  010300          TARSEC  010534
TCTR    010514          TDAY    010544 G        THR     010542 G
TMIN    010540 G        TMON    010550 G        TRIN    010046
TSEC    010536 G        TTYDAT  007236          TTYPAR  007330
TTYPA1  007614          TTYPA2  007650          TTYPA3  007606
TTYPA4  007442          TW      010530          TWCTR   010532
TYEAR   010552 G        V       010600          VINIT   010612
VISIB   010632 G        VISLUP  010642          VMAX    = 013560
VMIN    = 000062        VNEW    010560          VSTORE  010602
        = 010666
```

REFERENCES

1. Ingrao, H.C. and J.R. Lifsitz, "Characteristics of a Signal Data Converter for a Multi-Runway Visibility Measuring System," Report No. DOT-TSC-FAA-72-1, October 1971.

2. Ingrao, H.C. and J.R. Lifsitz, "Proposed Control Tower and Cockpit Visibility Readouts Based on an Airport-Aircraft Information Flow System," Report No. DOT-TSC-FAA-71-18, July 1971.

3. Coury, F.F., "A Practical Guide to Minicomputer Applications," IEEE Press, The Institute of Electrical and Electronics Engineers, Inc., New York NY, 1972.

APPENDIX II

ANALOG COMPUTER FOR CALCULATING RVR

This appendix describes the design and operation of an analog computer for calculating RVR developed by Dr. Joseph L. Horner. This work was sponsored by the Federal Aviation Agency and in compliance with the Project Plan Agreement (PPA) FAA-515.

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LIST OF ILLUSTRATIONS

1. ANALOG COMPUTER

1.1 INTRODUCTION

Two psychophysical equations are used to compute the RVR. The first is Allard's Law:

$$E_t = \frac{I_o \, (t_b)^{R/b}}{R^2} , \tag{1}$$

where E_t is the illuminance threshold (a property of the eye and background lighting conditions), I_o the luminous intensity of the specific target light (the runway edgelights), t_b the atmospheric transmittance measured over a pathlength b, and R the visual range. The FAA-accepted values of E_t are 1000 mile-candles for daytime, and 2 mile-candles for nighttime.

The second is Koshmieder's law,

$$C_R = C_o \, (t_b)^{R/b} , \tag{2}$$

where C_o is the contrast of a target, C_R is the observed contrast, and the factor $t_b{}^{R/b}$ is that described above. The limiting value of contrast threshold is taken to be 5.5% for aviation purposes.

The present FAA-computer selects the larger RVR value from equations (1) and (2) and displays the result. The computer is essentially a look-up table, where pre-computed value pairs of t_b and RVR are stored.

1.2 ANALOG COMPUTATION OF RVR

We begin by rewriting equation (1) in a consistent set of units:

$$E_t = \frac{I_o\ (t_b)^{R/b}}{(R/5280)^2}\ , \tag{3}$$

where E_t is in units of mile candles, R in feet, and I_o in candelas. To find the RVR, we must solve equation(3) for the transcendental variable R. Taking the common logarithm of both sides of (3) and rearranging terms;

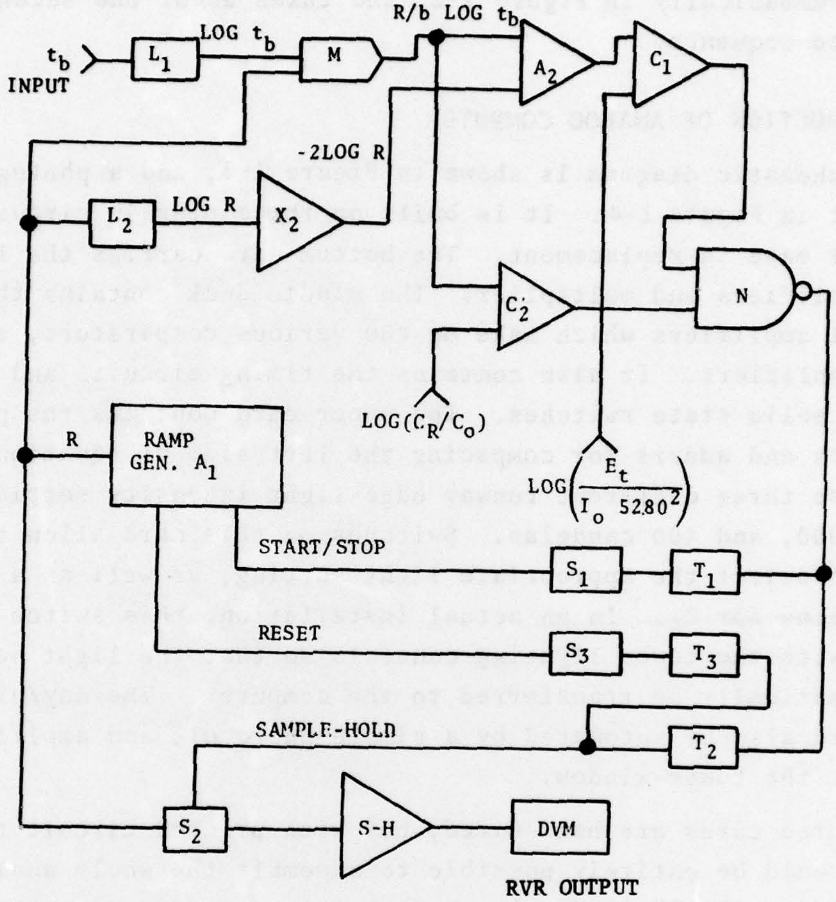
$$\log\left(\frac{E_t}{I_o\ (5280)^2}\right) = \frac{R}{b}\ \log t_b - 2 \log R. \tag{4}$$

The left side contains only fixed parameters, and the right side the running variable R, and the output of the field sensor t_b, expressed as a fraction always less than 1.0. Doing the same thing for Koshmieder's Law, equation (2) with C_o/C_R set equal to 0.055 gives,

$$-1.260 = \frac{R}{b}\ .\ \log t_b\ . \tag{5}$$

A block diagram of an analog system for solving these equations is shown in Figure 1-1. A ramp voltage is generated for R which increases linearly with time.

The two component parts of the right side of equation (4) are assembled by logarithmic amplifiers L1, L2, multiplier M, and operational amplifiers A2 and A1. Comparator C1 compares this with the left side of equation (4). This represents the Allard's Law computation. The Koshmieder computation is performed by comparator C2. The NAND circuit, N, fires after both equations have been solved, and stops the ramp generator through timer T1 and solid state switch S1, thus automatically making R correspond to the larger of the two RVR values. Timer T2, through its solid state switch S2, connects the R voltage to a sample-and-hold (S-H) circuit which in turn displays the RVR on a digital voltmeter (DVM). Timer T3 is started after the S-H circuit has acquired the new RVR value, and through S3 resets the ramp generator to a low value of range voltage. The entire



<u>NOTE:</u>

$T_1 = T_2 = T_3 =$ 555 Timers

$S_1 = S_2 = S_3 =$ FLT Switches

$L_1 = L_2 =$ Log Amplifiers

$A_2 = C_2 = C_1 =$ Comparators

Figure 1-1. Block Diagram of the Analog RVR Computer Developed at TSC. The input, t_b, Is Fed From a Transmissometer in the Field, and the RVR Output Is Displayed on the Digital Voltmeter (DVM).

cycle then repeats to find a new value of R. The timing sequence is shown diagrammatically in Figure J-2, and takes about one second for the complete sequence.

1.3 CONSTRUCTION OF ANALOG COMPUTER

The schematic diagram is shown in Figure 1-3, and a photograph of the unit in Figure 1-4. It is built on three plug-in circuit cards modules for ease in replacement. The bottom card carries the logarithmic amplifiers and multiplier. The middle deck contains the operational amplifiers which make up the various comparators, adders, and gain amplifiers. It also contains the timing circuits and their associated solid state switches. The upper card contains the potentiometers and adders for compsoing the left side of equation (4). Airports use three different runway edge-light intensity settings; 10,000, 2,000, and 400 candelas. Switches on this card allow the operator to select the appropriate light setting, as well as a day or night value for E_t. In an actual installation, this switch would interface with the tower lighting controls so that the light setting would automatically be transferred to the computer. The day/night switch would also be automated by a simple photocell and amplifier looking out the tower window.

The three cards are hand wired, but with printed circuit techniques it would be entirely possible to assemble the whole analog computer on one 5" x7" card. Because we only wanted to demonstrate feasibility, the Koshmieder equation solver, C2 and N, are not included in the package. This could be included and should present no problem as it uses quite straightforward circuitry.

1.4 PERFORMANCE

The range voltage R is scaled to 500 feet/volt. Since the operational amplifiers saturate at 10 volts, the maximum RVR computable is 5000 feet. The 50% voltage divider between the S-H circuit and DVM make the display read RVR directly in hundreds of feet. The lower limit in the present FAA transmissometer is a RVR of 600 feet. The chief limiting factor on the lower end of the RVR scale

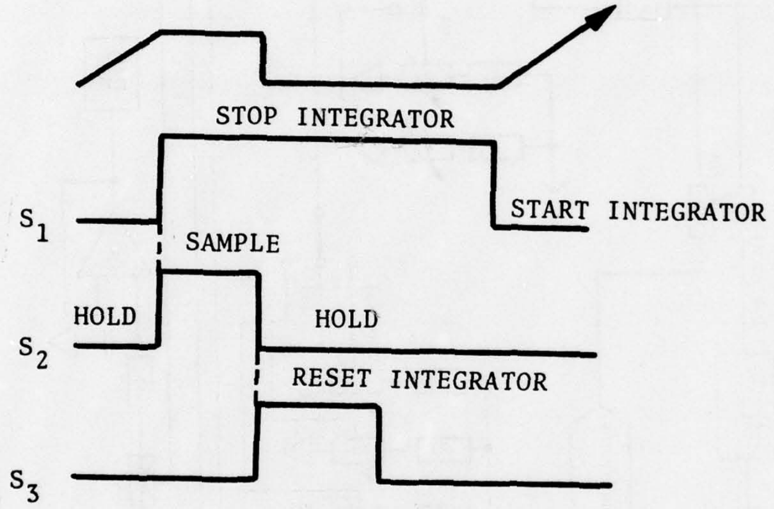
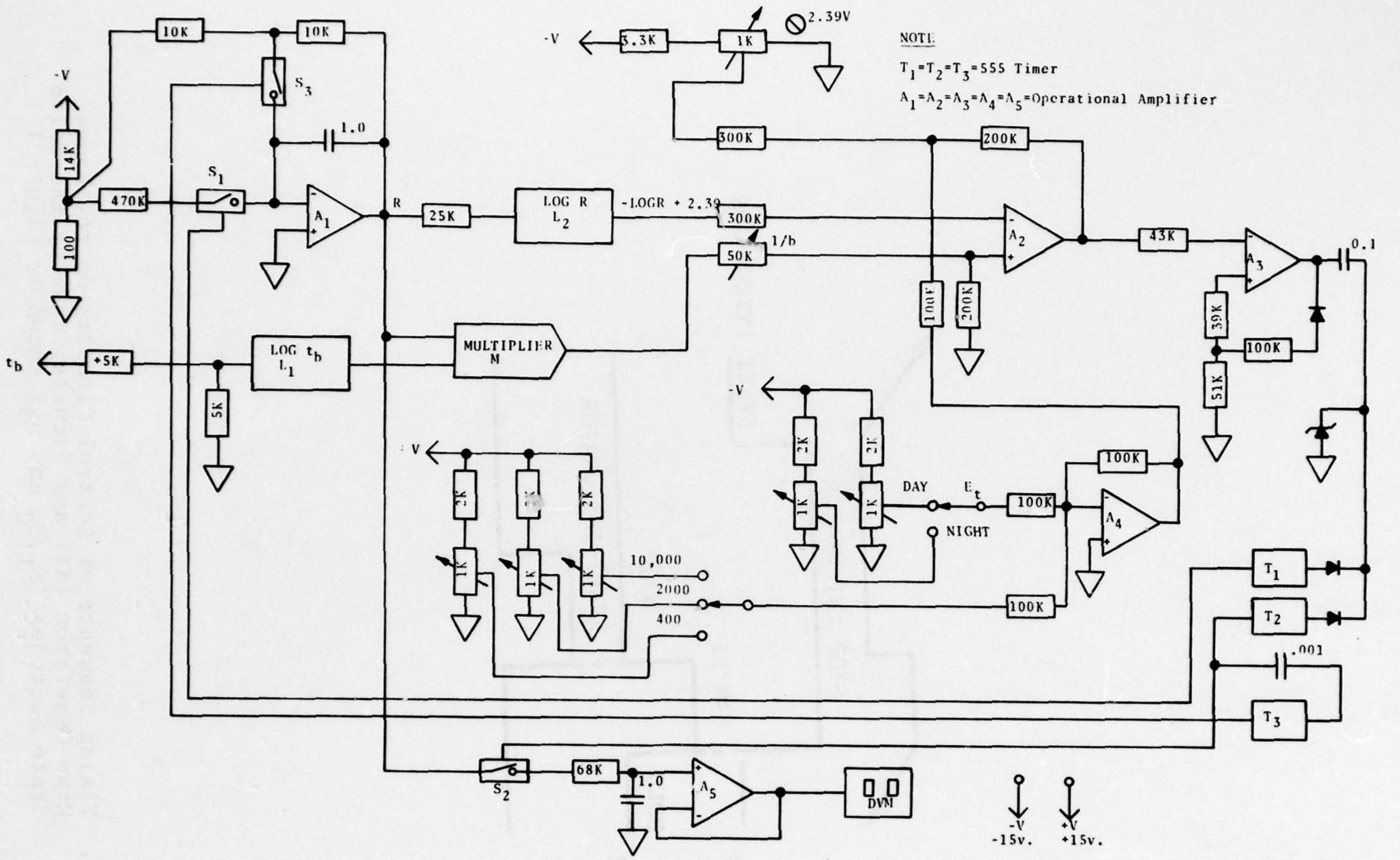


Figure 1-2. Timing Sequence of Control Circuits on the Range Ramp Generator (A1) and Signals Given by the Solid State Switches (S_1,S_2 and S_3) shown in Figure 1-1.



NOTE:

$T_1 = T_2 = T_3 = 555$ Timer

$A_1 = A_2 = A_3 = A_4 = A_5 =$ Operational Amplifier

Figure 1-3. Schematic Diagram of Analog Computer Developed at TSC for Calculating RVR by Allard's Law.

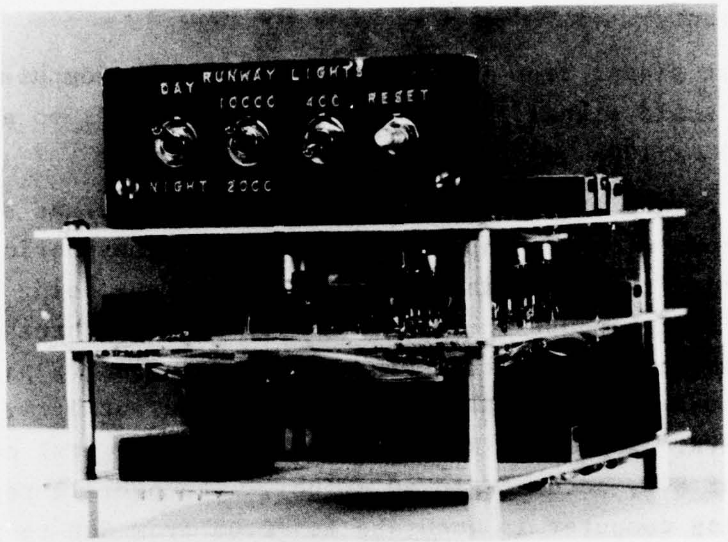


Figure 1-4. Photograph of Analog RVR Computer. Lower Card Holds the Log Amps and Multiplier, the Middle Card the Op Amps', Timing Circuits and Solid State Switches, and the Upper Card, the Op Amp and Pots for Setting the Parameters E_t and I_o.

in the analog computer is the logarithmic amplifier, L1, which computer log t_b. This particular amplifier, according to its manufacturer, has an accuracy of 0.2% over four decades of input signal and a 1.0% accuracy over six decades. Four decades ($t_b = 10^{-4}$) would correspond to a RVR of 233 feet, and six decades ($t_b = 10^{-6}$) corresponds to a RVR of 167 feet (daylight conditions and runway light settings of 10,000 candelas). Therefore, it can be seen that the analog computer can easily meet a requirement of 600 foot minimum RVR computation.

The input signal from the field sensor to the computer is a 10 volt full scale signal, i.e., 10 volts corresponds to a baseline transmittance of 100%.

One can regard the visibility computation device as a six-fold curve generator, with the input variable being atmospheric transmittance over a fixed baseline (t_b), and the output being the RVR in feet; six-fold because there are two illuminance threshold parameters in combination with three runway light intensity parameters. Figure 1-5 shows that typical analog computer output error as a function of the RVR. The exact RVR was taken from a digital computer calculation of RVR, accurate to ±0.5 feet. The overall result is that the analog computer is accurate to ±2.0% from 500 to 5000 feet (daylight conditions and 10,000 caldela runway light setting).

1.5 CONCLUSIONS

The device should be quite reliable, since it is all solid state with no moving parts. The temperature stability should be quite good, although this was not tested in the laboratory. The gain and reference current drift for the logarithmic amplifiers are ±0.05%/°C and 0.1%/°C respectively.

A limitation of this analog computer in its present configuration is that it does not provide RVR values in incremental steps as required by the FAA and ICAO. The FAA transmissometer reports in increments of 200 feet between 600 and 3000 feet and increments of 500 feet between 3000 and 6000 feet.

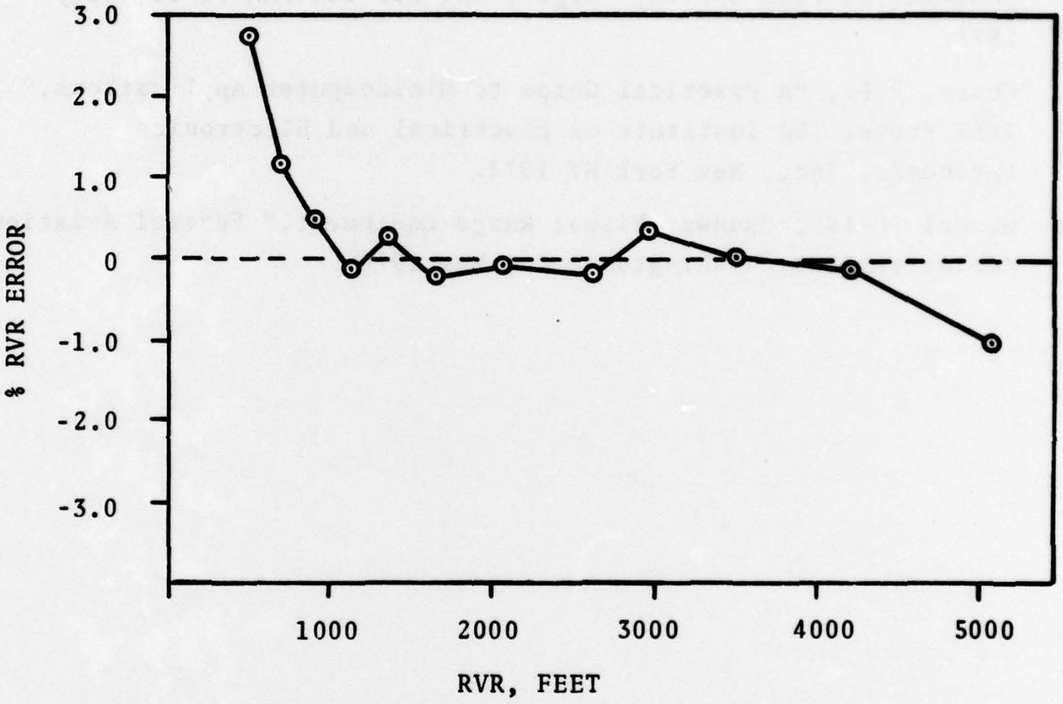


Figure 1-5. Output Error in Percent of Analog RVR Computer as Function of RVR Visibility in Feet.

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1. Ingrao, H.C. and J.R. Lifsitz, "Characteristics of a Signal Data Converter for a Multi-Runway Visibility Measuring System," Report No. DOT-TSC-FAA-72-1, Oct. 1971.
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4. Manual FC-199, "Runway Visual Range Equipment," Federal Aviation Administration, Washington D C , May 1970.