REPORT NO. DOT- TSC- FAA- 71- 18

PROPOSED CONTROL TOWER AND COCKPIT VISIBILITY READOUTS BASED ON AN AIRPORT-AIRCRAFT INFORMATION FLOW SYSTEM

HECTOR C. INGRAO, J. R. LIFSITZ
TRANSPORTATION SYSTEM CENTER
55 BROADWAY
CAMBRIDGE, MA. 02142

DEPARTMENT OF TRANSPORTATION
UNITED STATES OF AMERICA

JULY 1971
TECHNICAL REPORT

Details of illustrations in
this document may be better
studied on microfiche

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

Prepared for
FEDERAL AVIATION ADMINISTRATION
WASHINGTON, D. C. 20590

48

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.
DOT-TSC-FAA-71-18

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Proposed Control Tower and Cockpit Visibility Readouts Based on an Airport-Aircraft Information Flow System

5. Report Date
July 1971

6. Performing Organization Code
DOT/TSC/TER

7. Author(s)
Hector C. Ingrao, J. R. Lifsitz

8. Performing Organization Report No.

9. Performing Organization Name and Address
Department of Transportation
Transportation Systems Center
55 Broadway, Cambridge, MA 02142

10. Work Unit No.
R2125

11. Contract or Grant No.
PPA FA-15

12. Sponsoring Agency Name and Address
Federal Aviation Administration
800 Independence Avenue S.W.
Washington, D. C. 20590

13. Type of Report and Period Covered

14. Sponsoring Agency Code
RD-261

15. Supplementary Notes

16. Abstract

The problem of displaying visibility information to both controller and pilot is discussed in the context of visibility information flow in the airport-aircraft system.

The optimum amount of visibility information, as well as its rate of flow and display, depends both on the needs of the pilot during landing and on the air traffic control philosophy (tactical or strategic) chosen.

A rationale is provided to assist in the selection of flow rates and readouts. The relationship of visibility information to the magnitude of terminal information handled by the pilot is discussed. Several display formats are proposed, including one for the traffic controller and three different options for the pilot.

17. Key Words
Visibility
Air Traffic Control
Cockpit Display

18. Distribution Statement

19. Security Classif. (of this report)
U

20. Security Classif. (of this page)
U

21. No. of Pages
48

22. Price
$3.00

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

Preceding page blank

LIST OF ILLUSTRATIONS

Preceding page blank

INTRODUCTION

The Transportation Systems Center of the Department of Transportation is presently engaged in a study program for the Federal Aviation Agency titled "Visibility Measuring Devices". This report summarizes the results of one of those tasks under the program. The specific task statement reads as follows: Specify a technique which will allow direct cockpit readout of terminal visibility, to a pilot as well as to a tower controller.

At present the visibility information is supplied to the pilot on an advisory basis (non-control) only. In general, the nature, quantity, direction and general character of advisory information passing between ground station and aircraft are dependent upon the basic philosophy of the air traffic control system being employed. If strict ground control is exercised (the "tactical" approach), very little advisory data need be sent to the aircraft as ground control will make all decisions. However, in order to make optimum decisions, much more information on the aircraft status may have to be "telemetered" to the ground. On the other hand, if ground control is very liberal (the "strategic" approach) or if an electronic "see and be seen" philosophy is employed, then the aircraft pilot must be supplied with a considerable amount of advisory information on which to base his decisions.

This brief consideration based on the visibility information transmission system suggested by the Automated Data Interchange System (ADIS) Panel(1) of the ICAO suggests that the problem of data transmission is still not well defined. Therefore it is difficult to categorically recommend a given ground-to-air information data flow of which visibility is only a part. As a consequence, the specification of the hardware implementation to satisfy that flow cannot be uniquely defined and therefore several issues have to be resolved before proper suggestions concerning hardware implementation can be made.

CURRENT FAA VISIBILITY INFORMATION

WEATHER OBSERVATIONS

To provide the basis for operational decisions in aviation, accurate weather analysis and prediction are required. Weather forecasting depends on both human observations and a variety of instrumental measurements. Information gathered by ground personnel with the aid of relatively simple instruments includes local visibility, cloud base height, temperature and relative humidity, atmospheric pressure, wind velocity and precipitation.

More elaborate techniques are used to determine distributions of the above variables with height and to produce maps indicating both static and dynamic weather conditions. Among these techniques is radar (ground, airborne and sea-based) to determine cloud cover and precipitation patterns. Instruments carried aloft in balloons and rockets can give information on variation of wind velocity, air pressure, temperature, etc., with altitude. Finally, representing an important source of aviation weather information are the individual pilots and aircraft instruments which are carried for sensing atmospheric conditions during flight. Weather data is collected and distributed on a national scale through a cooperative network whose stations can be divided into the following categories(2):

	Approx. No. of Stations
National Weather Service (NWS)	290
Federal Aviation Agency (FAA)	210
Supplementary stations	180
Military	150
	830

In general the above stations make hourly observations of:

Sky cover	Wind velocity
Ceiling	Altimeter setting
Prevailing visibility	Obstructions to vision
Prevailing weather	General variability of conditions
Sea-level pressure	
Surface temperature	Runway visual range, where available
Surface dew point	

VISIBILITIES

There are basically two kinds of visibilities: the first one is measured by human observation and is generally referred to as prevailing visibility. The other is the result of instrumentational determinations and calculations and is referred to as Runway Visual Range (RVR) and Runway Visibility (RVV).

Prevailing Visibility: This condition of visibility is the greatest horizontal visibility prevailing throughout at least half of the horizon circle (not necessarily continuous). Prevailing visibility is determined at either the usual site(s) or from the control tower level. Two variations which are sometimes used are:

Variable Prevailing Visibility. This is a condition during which the prevailing visibility is less than 3 miles and rapidly increases or decreases by one or more reportable values during the period of observation.

Sector Visibility. The greatest distance within a specified portion of the horizon circle, having essentially uniform visibility, at which reference markers can be seen and identified.

The observation sites are NWS stations or, in some cases, the control tower at an airport. The actual measurements are made by sighting reference markers. During the day, these markers consist of certain objects and the sharpness with which the markers stand out (contrast) is an indication of the visibility. At night unfocused lights of moderate intensity at known distances are used.

Visibility is measured and reported in statute miles. In practice, the values are reported in discrete steps, with the size of the steps increasing with the visibility. These "reportable" values of visibility are tabulated in Table 1.

Table 1. Visibility Values Reportable and Corresponding Step Sizes

REPORTABLE VISIBILITY (miles)	STEP SIZE (miles)
0 1/16 1/8 3/16 1/4 5/16 3/8	1/16
3/8 1/2 5/8 3/4 7/8 1 1 1/8 1 1/4 1 3/8 1 1/2 1 5/8 1 3/4 1 7/8 2	1/8
2 2 1/4 2 1/2	1/4
2 1/2 3	1/2
3 4 5 . . . . , 15	1
15 20 . . . . , 40, etc.	5

The instrumental visibility values are defined as follows:

Runway Visibility Value (RVV). Runway visibility is the visibility along an identified runway. Where a transmissometer is used for measurement, the instrument is calibrated to indicate values statistically comparable to those that would be observed by an observer visually, using as targets either dark objects against the horizon sky during daylight or unfocused lights of moderate intensity at night.

Runway Visual Range (RVR). Runway visual range is the maximum distance in the direction of take off or landing at which the runway, or the specified lights or markers delineating it, can be seen. The point of observation is taken to be along the runway center line and at a height corresponding to the average eye-level of pilots at touchdown.

In the United States, runway visual range (RVR) is a value determined normally by instruments located alongside the runway, about 14 feet higher than the centerline. These instruments are calibrated with reference to the sighting of high intensity runway lights or the visual contrast of other targets - whichever yields the greater visual range.

Runway visibility is considered variable when it is less than 2 miles and its range of variability (transmissometer extreme values) in the past 10 minutes includes four or more reportable values. RVR values are used when the prevailing visibility is 1 mile or less. The reported increments are in feet, for visibilities less than 1000 feet, from 1000 feet to 4000 feet increases are in steps of 200 feet, from 4000 feet to 6000 feet in steps of 500 feet. Above 6000 feet the value 6000+ registers.

The measurements by a transmissometer take about 48 seconds, and the data conversion another 5. This means that the RVR values are visibilities averaged over 48 seconds and the values are updated and displayed every 53 seconds. It should be pointed out that during the 53 seconds period the last RVR value remains stored in the RVR system in such a way that when a given runway is selected on the remote digital display unit this RVR value is immediately displayed. These so-called One-Minute RVR values are considered valid only for immediate use for local air traffic.

Another concept is the Ten-Minute RVR value. This consists of the lowest and highest RVR value recorded during the last 10 minutes and based on a high intensity runway light setting of 5, regardless of the actual setting. As such, it is a measure of the variability of the visibility. The Ten-Minute RVR values are obtained directly from the recorder which makes a permanent ink tracing of the transmittance measured by the transmissometer.

FAA RUNWAY VISUAL RANGE MEASUREMENT TECHNIQUE AND DATA DISSEMINATION

INTRODUCTION

The most critical and potentially dangerous weather for aviation operations occurs when visibility conditions are marginal. Deciding whether or not to land an aircraft, in the presence of patchy fog or low clouds, requires accurate and continually-up-dated information about the visibility in the final approach zone and along the particular runway involved. The need for accurate instrumental measurements of visibility is therefore obvious.

The transmissometer, first developed by Douglas and Young (3) at the National Bureau of Standards in 1942, measures the atmospheric transmittance over a fixed distance (usually 250 feet) with a light source and photodetector at opposite ends of the sampled path. First accepted for airport operations in 1952, the transmissometer now 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.

MEASUREMENT TECHNIQUE

To understand better the capability and the limitations of the transmissometers in use by the FAA it is useful to understand the theory and realization of the instrument. The "Preliminary Instruction Book -Runway Visual Range (RVR) System" (4) prepared for the FAA gives a concise description of the transmissometer and a block diagram of the measuring system (Figure 1). 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 photo-electric receiver located at the opposite end of the base line (see Figure 2). The receiver translates the intensity of the received light into a pulse rate by using the photo-electric current generated in a vacuum photoelectric cell to charge a capacitor. When a given charge accumulates on the capacitor, resulting in a definite voltage across the capacitor, a gas discharge trigger tube connected across the capacitor breaks down delivering a large impulse to

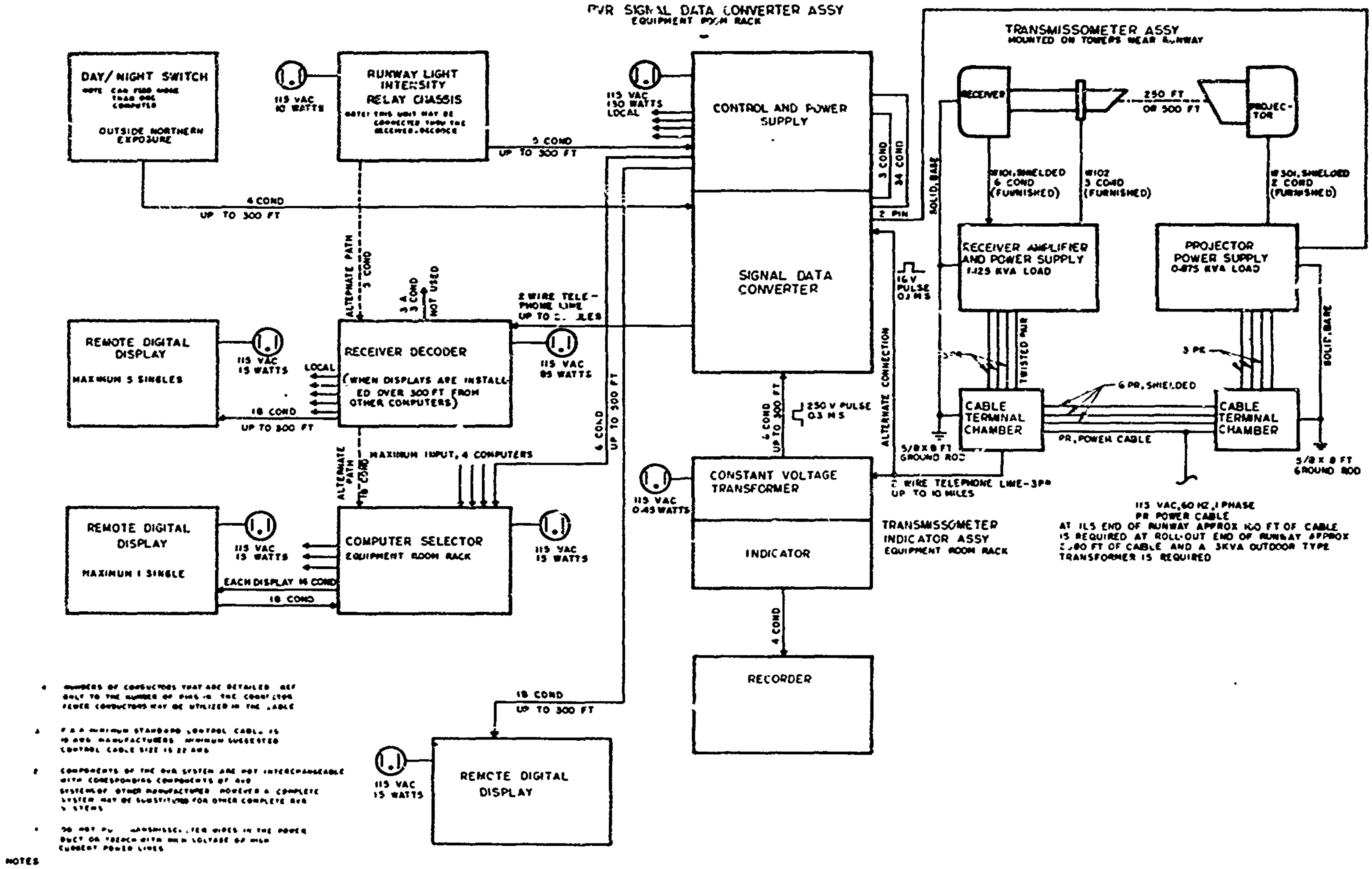


Figure 1. Block Diagram of the Current FAA RVR Measurement System (Ref. 4).

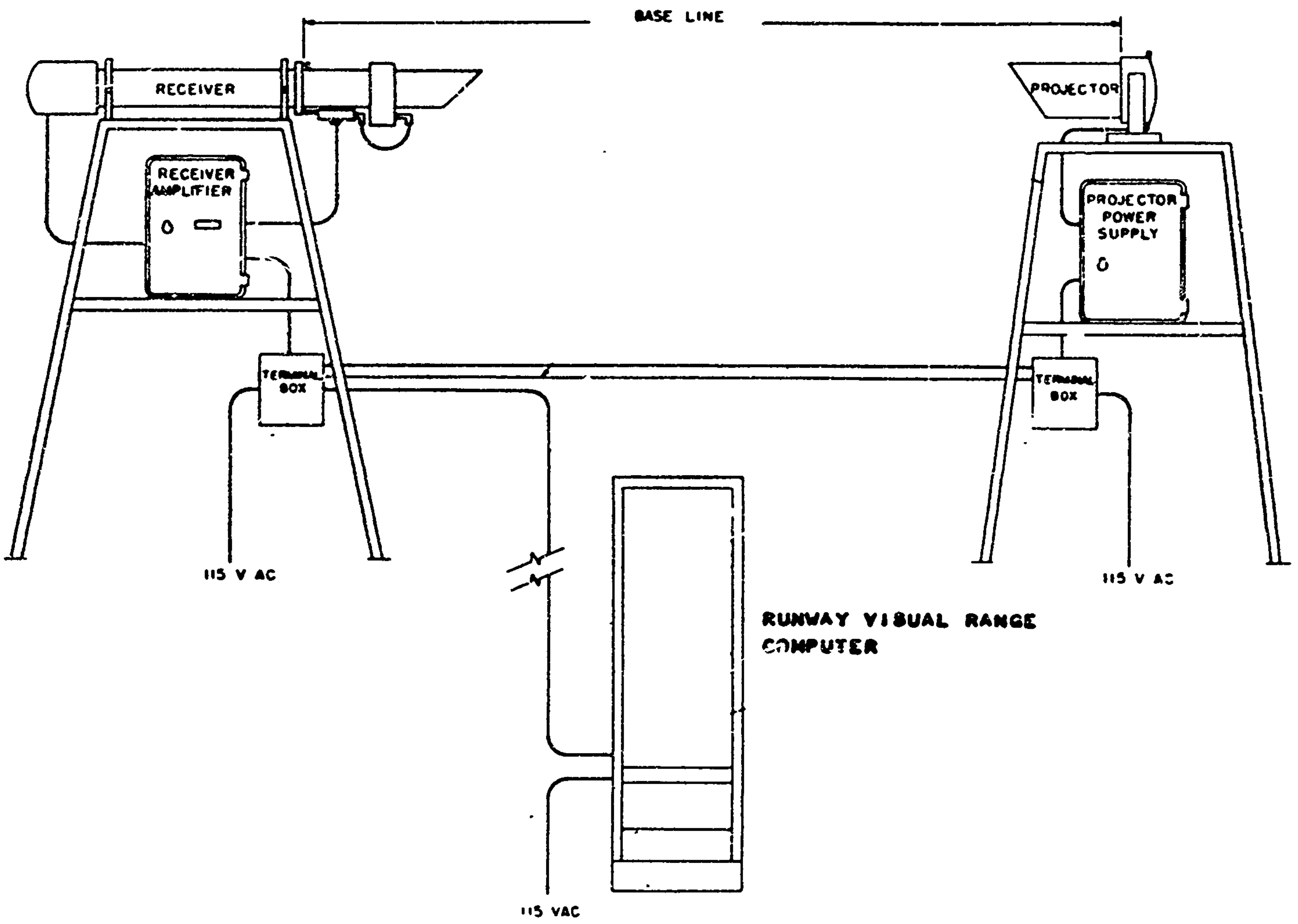


Figure 2. Schematic Showing the Projector, Receiver and RVR Computer.

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 photo current 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/minute for 100% transmission, i.e., a clear day free of smoke, dust or haze, in the base line optical path. Any rain, fog, smoke, dust or haze, in the base line 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 from 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 scatter 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 on any remote indicator chassis connected to the signal data converter control and power supply. More than one transmissometer may be utilized per runway as required for operation at runways approved for lower visibility operation".

The 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 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. Whenever the count in the transmissivity register is equal to one of the stored values in 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 contents of this five bit counter are decoded to yield a signal on one of 21 lines corresponding to the 21 solutions. These lines are then 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. The receiver decoder receives this binary transmission storing it in a shift register following a synchronization bit corresponding to an interruption in line voltage. At the end of the message, the line remains high, signifying the end of message and resulting in a strobe to display the remote indication. If a parity error is detected or the line is interrupted, the receiver decoder automatically forces the display to read ___ ___ E. During the time which the signal data converter 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 signal data converter 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 possible RVR values. In order to test all tables, a manual table select is available in conjunction with the first test."

DATA DISSEMINATION

In this section we discuss the dissemination of RVR data flow in an Airport-Aircraft system and refer as a specific example, to the dissemination at Logan airport, Boston (see Fig. 3). The visibility measurements and reporting are generally the responsibility of the National Weather Service (NWS) and the Federal Aviation Agency (FAA) and in some instance only of the FAA. If the visibility is 3 miles or better it is usually measured and reported by the NWS. This data is transmitted to the control tower via Tel Autograph or similar system. This data is relayed to the arriving aircraft by the approach controller via voice radio link (approach frequency).

From 1 to 3 miles visibility, personnel in the CAB take visual observations using markers. These observations are supplied to the approach controller; also to the NWS via Tel Autograph. Below 6000 feet visibility, measurements are made by the personnel in CAB using markers and also by the transmissometers along the runway. The visibility values are expressed in RVR scale when measured with the transmissometer. These observations are supplied to the NWS via Tel Autograph.

The RVR data is distributed from the RVR computer (see Fig. 4) to the controllers in the control tower (CAB) as numerical readouts and then via voice link to the pilot in the aircraft. This readout is given by the Remote Display Units. A detailed layout of such a Display Unit located in the CAB at Logan airport is shown in Figure 5. A partial view of the Final Controller's Console showing the location of the RVR Remote Digital display unit is given in Figure 6.

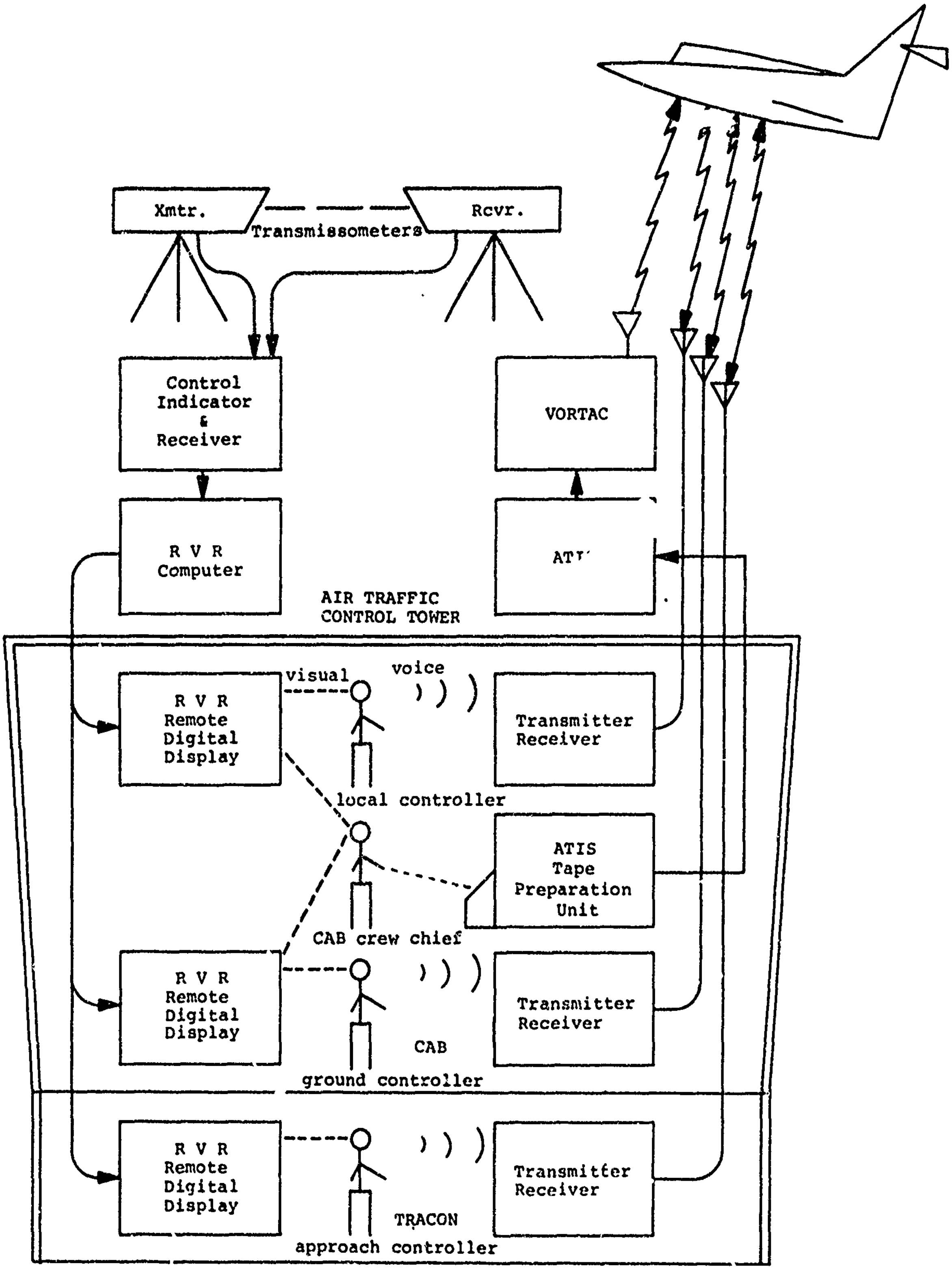


Figure 3. Block Diagram of RVR Data Flow in an Airport/Aircraft System.

The RVR Remote Display is energized through a toggle switch. The display has the capacity to monitor up to sixteen individual instrumented runways, two runways at a time (one transmissometer each), as selected by the operation of either of the two "RUNWAY" selector switches.

The RVR displays installed at Logan Airport are set for runways No. 4 and No. 33 which are instrumented with two 250 foot baseline transmissometers. The RVR values from the RVR computer appear in the two oval windows located in the center of the display unit. The RVR is displayed in hundreds of feet from 600

Figure 4. View of the RVR Computers Installed at Logan Airport, Boston, Massachusetts.

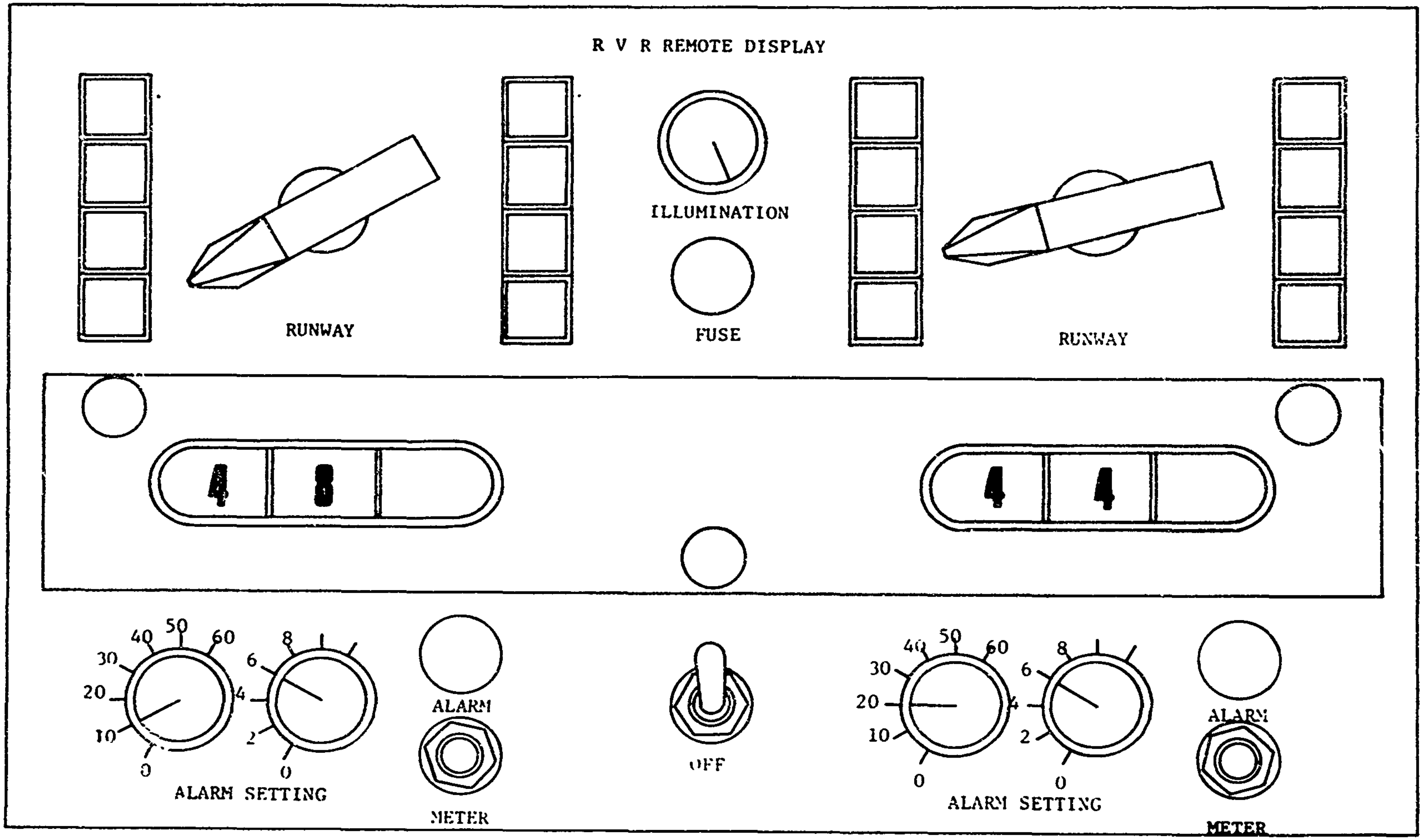


Figure 5. Detailed Layout of Current FAA RVR Remote Digital Display Unit. (Logan Airport, Boston, Massachusetts).

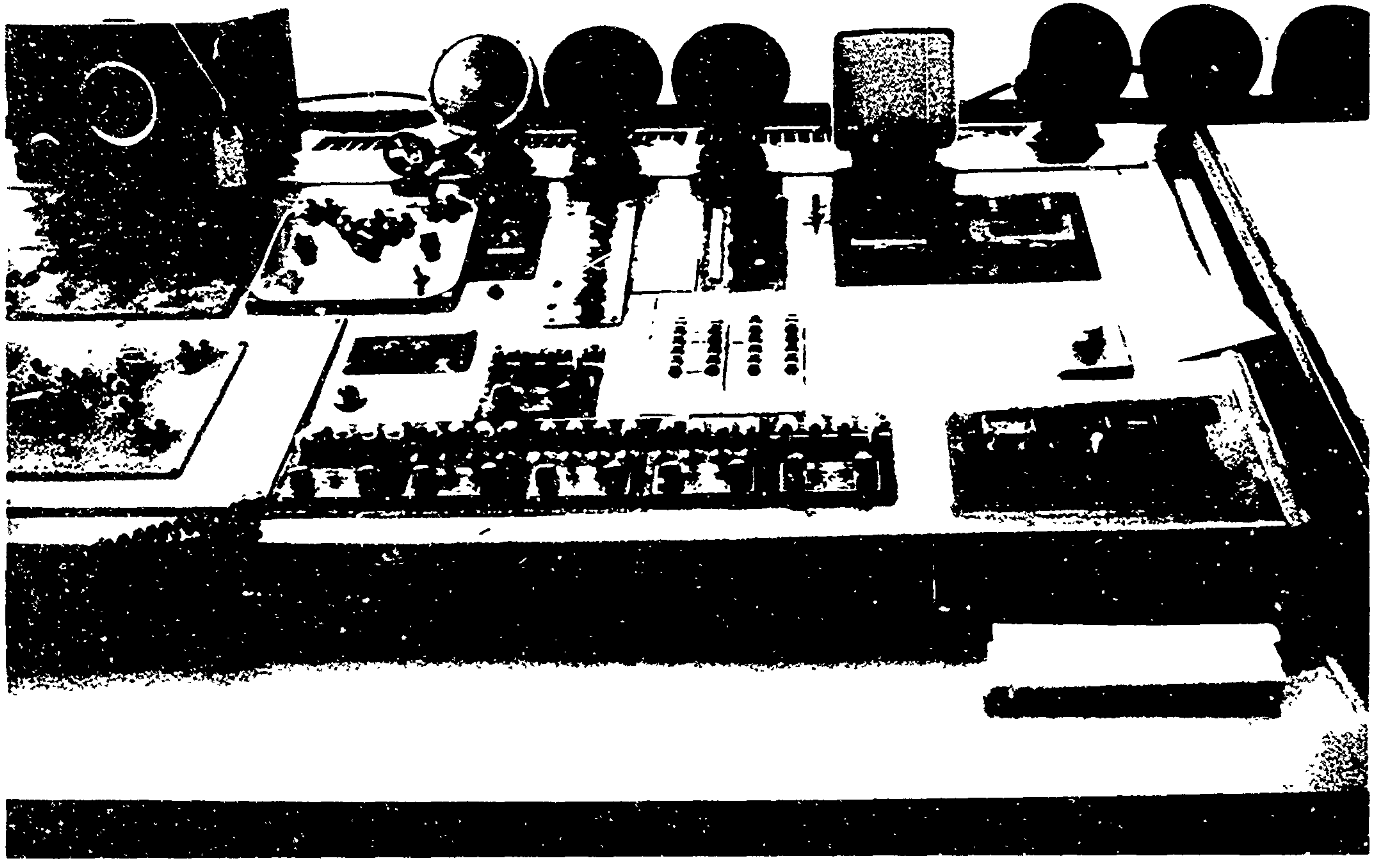


Figure 6. Partial View of the Local Controller's Console Showing the Location of the RVR Remote Display Unit (Logan Airport, Boston, Massachusetts).

feet (reading 6) up to a maximum of 6000 feet (reading 60). These 250 foot baseline systems have 200 foot increments from 600 to 3000 feet RVR and 500 foot increments from 3000 to 6000 RVR*. The lower portion of the display is designed to provide an "ALARM" in the form of an indicator light to the controllers in the event pre-selected minimum values of RVR as set by the controller and as measured by the transmissometer are detected by the RVR computer. The "ALARM" SETTING" knobs are used by the controllers to set the alarm level. The "ILLUMINATION" control adjusts the edge illumination of the display panel.

Approach Controller to Pilot. The approach controller has at his disposal an RVR remote digital display unit which gives the RVR values for the given runway. When the prevailing visibility or RVR is 1 1/2 miles or less or when RVR is 600 feet or less the visibility information is supplied to the pilot by the approach controller via voice link (approach frequency).

Local or Final Controller to Pilot. The local controller also has at his disposal an RVR remote digital display unit (see Figure 6). RVR readings below 4000 feet are supplied to the pilot via voice link by the local controller. This takes place from the time that the aircraft is transferred by the approach controller to the local controller.

Ground Controller to Pilot. The responsibility of the ground controller consists in providing advisory information to the pilot during taxiing from the airport terminal to the runway or vice versa. The FAA Terminal Air Traffic Control manual (5) describes the departure information to be supplied by the ground controller to the pilot (via voice link), as follows:

"Provide departure information as appropriate to a departing aircraft. Omit information currently contained in the ATIS broadcast if the pilot states the appropriate ATIS code. Omit a, b, and c if the pilot states "having numbers" or a similar phrase. Issue departure information by including the following:

a. Runway in use.
b. Surface wind.
c. Altimeter setting. Unless specifically requested by the pilot, this need not be issued to local aircraft operators who have requested this omission in writing or to scheduled air carriers.
d. Time, when requested.

---

*In other airports 500 foot baseline systems are installed having 200 foot increments from 1000 to 4000 feet RVR. From 4000 to 6000 feet RVR 500 foot increments.

e. Deleted.
f. Issue the official ceiling and visibility to a departing aircraft before take-off, as follows:

   (1) To a VFR aircraft - when weather is below VFR minima.
   (2) To an IFR aircraft - when weather is below that published as the highest takeoff minima for the airport or, if no take-off minima are published, when weather is below VFR minima.

g. Taxi information, as necessary. You need not issue taxi route information unless the pilot specifically requests it."

In cases of reduced visibility the ground controller denies take-off in accordance with the following procedure and criteria (5):

"a. Inform the aircraft of the visibility and do not issue take-off clearance to an air carrier or commercial aircraft carrying passengers or property for compensation or hire when any of the following conditions exists:

   (1) When both touchdown and rollout RVR digital displays are available for the departure runway and either of the following conditions exists:

      (a) Touchdown RVR is less than 1,600 feet and rollout is less than 1,000 feet.
      (b) Touchdown RVR is less than 1,200 feet regardless of the rollout RVR indication.

   (2) If only touchdown RVR is available for the departure runway and either of the following conditions exists:

      (a) At locations with an RVR digital display, RVR is less than 1,600 feet.
      (b) At locations with an RVR meter, RVR is less than 2,000 feet and prevailing visibility is less than 1/4 statute mile.

   (3) If RVR is not available and either RVV or RVO is available for the departure runway, RVV or RVO is less than 1/4 statute mile.
   (4) If RVR, RVV or RVO is not available for the departure runway, the prevailing visibility for the airport of departure is less than 1/4 statute mile.

Figure 7 summarizes the current visibility information flow in an Airport-Aircraft System (Logan Airport-Boston).

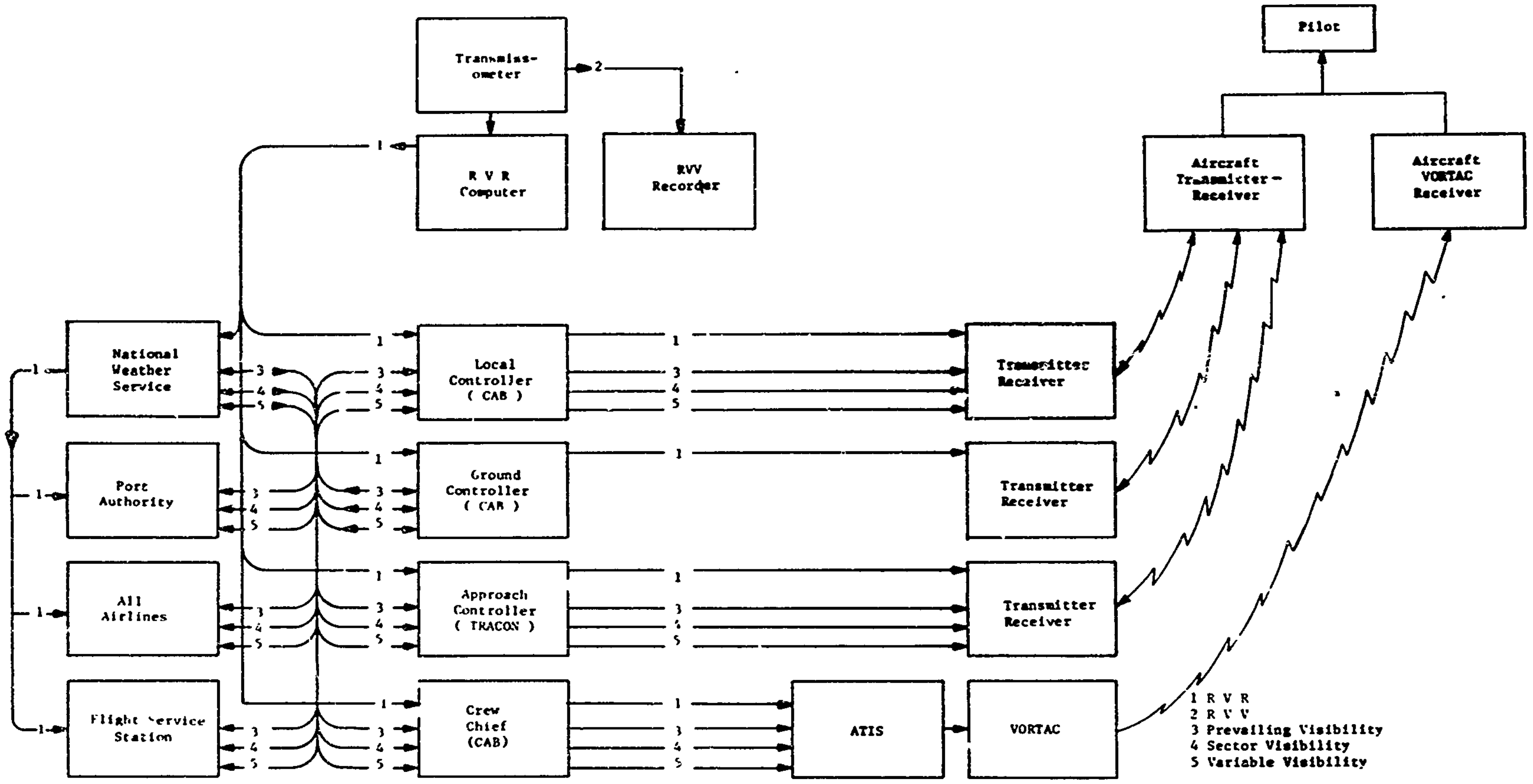


Figure 7. Block Diagram of the Current Visibility Information Flow in an Airport-Aircraft System (Logan Airport, Boston, Massachusetts).

Automatic Technical Information Services (ATIS) to Pilot. The ATIS is the continuous broadcast of recorded non-control information in selected high activity terminal areas. Its purpose is to improve controller effectiveness and to relieve frequency congestion by automatic repetitive transmission of routine information.

The information supplied by ATIS includes visibility (RVR or prevailing visibility, whichever is applicable), ceiling, wind, altimeter setting, instrument approach and runways in use. This information is continuously broadcast on the voice feature of a TVOR/VOR/VOR-TAC located at or near the airport, on a discrete VHF tower frequency. Pilots arriving at or departing from the terminal area can receive the continuous ATIS broadcasts. ATIS broadcasts are recorded on magnetic tape with a 2 1/2 minutes message. ATIS broadcasts will be updated when there is a significant change in information contained therein. No transmission takes place during updating which takes approximately 2 1/2 minutes. Pilots should listen to ATIS broadcasts whenever ATIS is in operation and should notify the controller that they have received the ATIS broadcast.

PROBLEMS IN CURRENT VISIBILITY INFORMATION FLOW

Problems in current procedures for providing visibility information to the airport-aircraft system can be found in the measurement of visibility, transmission or dissemination of the measured data, as well as display. The limitations of the present visibility procedures are most noticeable in low visibility conditions (i.e., CAT II, III). These limitations appear as operational problems in the CAB and cockpit and are important from the point of view of safety and legality. A paper presented to the 15th Air Safety Forum (6) by Captain R. H. Beck listed a number of such problems. We have selected those comments most relevant to visibility information and summarized them below.

1. The measurement of RVR, even when accurately representative of surface visibility, can be misleading if taken to represent slant visibility from the cockpit at decision height. This is especially true in fog conditions.

2. The precision and rate of updating of visibility information (and other kinds of flight information) are presently inadequate below a height of about 200 feet. At the 100 foot decision height, the quality of information is often unacceptable.

3. With the present-day panel instruments and workloads, flight crews may be approaching the point where "data saturation" can result in a deterioration of performance and the source of potentially serious errors. Therefore, it is essential that only the most relevant information be supplied to the cockpit and in a form which is immediately useful.

4. As landings become legal with lower and lower visibility (Cat. II, III), the time interval between decision height and threshold becomes shorter and shorter, measurable in seconds. This puts stringent demands on the pilot's responses and further reduces the amount of information that he can usefully comprehend during these moments. For example, the average time for refocusing the eye from distant to short range vision has been found to be about 2.5 seconds. Thus, once the pilot's eyes have left the instrument panel to make visual contact with the runway at the decision height, they will most likely not return again to the panel during the descent.

5. Until the pilot sees the runway threshold and an aiming point beyond, he cannot properly judge his orientation for a safe approach. With RVR of 1200 feet, he would have to be as low as 70 or 80 feet above the ground to obtain this judgement. Thus he would be below the decision height of 100 feet before having complete confidence in his approach decision. Beck points out that, under certain conditions, this kind of situation might have legal implications.

In addition, Beck points to some conclusions of the Aviation Weather Research Project (a joint program between the U.S. Weather Bureau and the FAA carried out during 1959-1961). One of the conclusions was that a single RVR value, determined from a transmissometer located at the ILS touchdown point, is not always representative of visual range encountered by a pilot during other stages of landing and takeoff operations. This is consistent with recommendations concerning the need for at least three transmissometer systems per runway (touchdown, midpoint and rollout) under CAT II and III conditions. Many pilots have indicated that such information, properly displayed, would provide an important psychological boon, giving confidence to a pilot landing in patchy or variable fog conditions. The Aviation Weather Research Project also concluded that it should be feasible to arrive at an optimum intensity for approach and runway lights, by automatically coupling the intensity control with visibility information. Visibility-dependent light intensities could therefore make a significant contribution to airport safety.

ASSESSMENT OF VISIBILITY INFORMATION REQUIREMENTS DURING LANDING

INTRODUCTION

In order to discuss a visibility display system for the cockpit of a modern aircraft, it is important to understand how, when and why the displayed information is to be used. The most crucial need for visibility information is during landing. With this in mind, let us investigate the relevant aspects of a typical landing.

Under good visibility conditions, day and night landings are routinely performed under Visual Flight Rules (VFR). In such cases, the horizontal visibility is at least 3 miles as judged by the personnel at the CAB or the NWS. For lower visibility conditions, such as CAT I and less, landings are performed under Instrument Flight Rules (IFR). Under such conditions, the law requires that visual contact with the runway must be established by the decision height or else a missed approach must be executed.

Let us consider the time scale and relevance of visibility information during a landing. This should help to get a feeling for how much time a pilot has to read a display, how much information should be transmitted, how often it should be updated, and finally what actions can be taken based on visibility information.

DESCRIPTION OF LANDING RELEVANT TO VISIBILITY

Let us analyze the landing of a typical jet aircraft of about 120 tons and 145 feet wingspan on a typical runway (8000 to 12000 ft. long). The aircraft will approach the runway along a 2°-3° glide path with a speed of about 140 knots or 236 ft. sec^{-1}. On a 3° glide path, this corresponds to vertical downward velocity component of 12 ft. sec^{-1}. By touchdown, this vertical component must be reduced to about 2-3 ft. sec^{-1}. which is accomplished by the flare maneuver. The time and distances involved are shown in Table 2. This table shows how fast the whole landing process takes place. For example, in CAT II landing, at the 100 ft. decision height and with a 1200 ft. RVR, the aircraft is only about 4 seconds from the runway threshold, which is 1000 ft. away. This situation would require an almost instantaneous decision, because the runway

TABLE 2. Time from Touchdown for Different Distances from the Runway Threshold and the Height above Runway During Instrument Landing of a Commerical Jet Aircraft

	Dist. from Runway Threshold, D	Height above, H	Time from Touchdown, T
Outer Marker	- 6 miles	1600 ft.	- 2.5 min.
Middle Marker	- 3500 ft.	200 ft.	- 23 sec.
Inner Marker	- 1000 ft.	100 ft.	- 12 sec.
Flare Decision	- 500 ft.	75 ft.	- 10 sec.
Runway Threshold	0	50 ft.	- 8 sec.
Flare begins	+ 500 ft.	30 ft.	- 6 sec.
Descent	+ 1000 ft.	20 ft.	- 4 sec.
Touchdown	+ 1000 ft.	0	0
Nose Wheel Contact	+ 1600 ft.	0	
Mid Point	+ 3650 ft.	0	
Roll Out	+ 6300 ft.	0	

is visible a little less than one second before the decision height is reached.

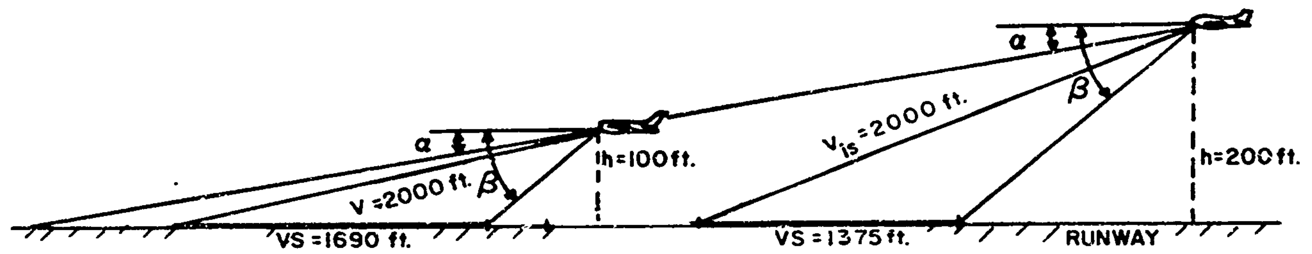
During the IFR approach, the co-pilot looks for visual cues. If visual contact before the decision height is made, this is signalled to the pilot and he proceeds with the landing, guided by the visual navigation aids of the airfield. If visual contact is not made, a missed approach is executed. This is a simple matter, since the landing aircraft is in about the same configuration as required for take off. To shift the attention from cockpit to outside or vice versa, requires a visual accommodation change which requires from 0.5 to 1 second. This is a fairly long time on the time scale of the final approach.

CHANGES IN VISIBILITY

To provide some idea as to how often visibility information is to be updated and why, let us look at the time scales of some phenomena associated with visibility. For example in given fog conditions with RVR values of 1200 ft. to 1800 ft., instabilities and fluctuations in RVR values up to 3600 ft. (measured with a 250-ft. base transmissometer) are not uncommon. This gives rise to the very dangerous situation of a significant decrease of visibility during the final portion of the approach.

During homogeneous and constant visual conditions, the steadily increasing visual segment a pilot sees during descent is a purely geometric effect as shown in Figure 8-a. In the case depicted, an aircraft is descending in a 3° glide slope, with an assumed slant visual range of 2000 ft. and a cockpit cut-off angle of 15°. We note that the visual segment has increased from 1375 ft. to 1690 ft. during the approximately 8 seconds between 200 to 100 ft. altitude. Taking the same assumed conditions but with a temporal or spacial inhomogeneity in visibility, the slant visual range changes from 2000 ft. at the 200 ft. decision height to about 1000 ft. at the 100 ft. altitude, the visual segment decreases from 1375 ft. to about 700 ft. (see Figure 8-b).

Since the length of the visual segment is an important visual cue for the pilot, a sudden decrease of the segment may result in a response to increase the rate of descent and undershoot touchdown. The importance of such psychological effects varies from pilot to pilot.



a. homogeneous and constant visibility conditions.

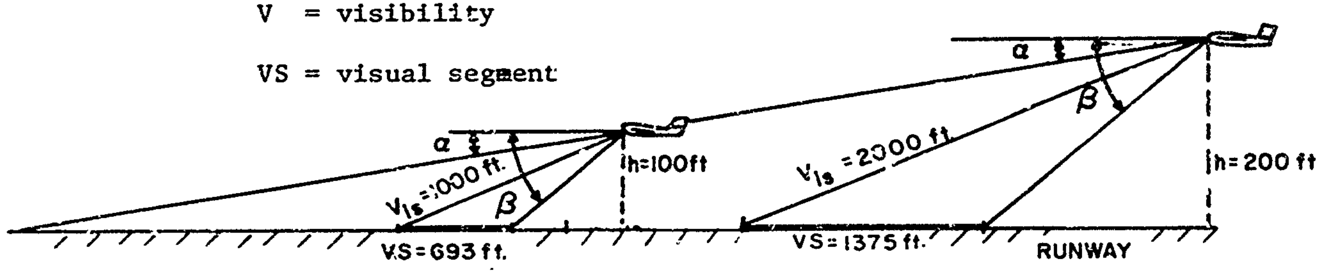
α = glide slope angle, i.e 3°

β = cockpit cutoff angle, i.e 15°

h = height

V = visibility

VS = visual segment



b. inhomogeneous and/or changing visibility conditions

Figure 8. Visual Segment Changes During Landing

PROPOSED VISIBILITY INFORMATION AND FUTURE WEATHER INFORMATION

INTRODUCTION

In this section, we develop a rationale to reach a recommendation on the visibility information and read out for the controller and the pilot. It is clear that the visibility information has to satisfy the operational definitions and requirements of the FAA (CAT I, II and III) and the needs of the pilots during the most important part of the landing maneuver. Visibility also is part of the terminal information and we consider it as such. The recommendations in this section are based on these premises.

ICAO VISIBILITY CATEGORY DEFINITIONS

The present visibility requirements for aircraft landings are simply stated. Under good visibility conditions (ceiling exceeding 1000 feet and horizontal visibility at least 3 miles) day and night landings are routinely performed under VFR. For reduced visibility the International Civil Aviation Organization (ICAO) defines three categories of visibility for landings of civil aircraft under IFR(7):

Category I: Landings may be conducted with a decision height of 200 feet and RVR of 2400 feet or greater. The decision height is the height at which a decision must be made, during an instrument approach, to either continue the approach or execute a missed approach.

Category II: Aircraft operations are permitted as low as a 100 feet decision height and 1200 feet RVR. Ground measurements of ceiling are not required. Category II landings have been permitted since 1967. Both the aircraft and the airports involved in Catetory II operations must satisfy certain requirements. The aircraft must have both barometric and electronic means of accurately establishing height as well as two pilots and adequate windshield cleaning equipment. The airports must be equipped with two transmissometers and have outer, middle, and inner marker beacons and an adequate ILS.

Category III: The landing minima are subdivided as follows:

III A: Operation to and along surface of runway, with minimum RVR of 700 feet. Pilot must have visual reference during final phase of landing.

III B: Operation to and along surface of runway and taxiways, with minimum RVR of 150 feet. Pilot must have visual reference during taxiing.

III C: Operation to and along surface of runway and taxiways. Zero visibility.

All major airports in the U.S. are instrumented for CAT I visibility conditions. At this time only O'Hare, J.F. Kennedy, Los Angeles, Atlantic City (NAFEC) and Atlanta have instrumented runways for CAT II conditions. So far there is no implementation for CAT III conditions.

WEATHER DATA AND THE AMOS III-70

The FAA will soon have at its disposal unique equipment which will facilitate the dissemination and display of meteorological information, including RVR. The development of this system, the so-called AMOS III-70(8), is under the auspices of NWS.

The U.S. Weather Bureau (now the NWS) first began using automatic weather equipment in 1945. In 1953 the Weather Bureau developed the equipment for the first Automatic Meteorological Observing Station (AMOS). As the stations became more sophisticated, particularly in data transmission, successive improvements were known as AMOS I,-II, and -III. At present most of the 21 AMOS III installations are still operational, but their effectiveness is diminished due to antiquated equipment. There is considerable range in the complexity of the AMOS stations. Some simply record raw data whereas the most sophisticated use a special-purpose computer for automatic data-reduction. All the stations have teletype transmission facilities and measure the following parameters: temperature, humidity, pressure, wind speed and direction, and precipitation.

The Weather Bureau, in 1965, decided to develop the AMOS III-70, an up-dated state-of-the-art version of the AMOS III. Modular in concept, the AMOS III-70 uses specialized integrated circuit cards for analog-to-digital conversion of the output of various sensors. For example, a particular card provides A/D conversion of temperature data; the digital output from the AMOS III-70 can then be fed to a remote digital display panel. In addition, other cards provide for conversion from, say digital to Baudot coding, which can then feed a teletype circuit. The latter makes available hard copy printouts.

The parameters which can be reported by AMOS III-70 are the same as for the other AMOS stations given above. In addition, future refinements are planned which will report more specific weather details. Visibility and cloud height are two which will be of particular interest to aviation. Since a manual input module will be available at aviation stations, observers can enter remarks on cloud cover, visibility, obstructions to visibility and other relevant information.

The FAA will supply AMOS III-70 equipment to CABs at a limited number of airports in the near future.

At the Air Traffic Control Tower. A block diagram of the proposed AMOS-III-70 remote digital display at the CAB is shown in Figure 9. The panel has a capacity of nine data displays eight of which are allocated and one is a spare, as shown in the block diagram. One display is allocated to read visibility from the FAA, RVR or SVR measuring system. As planned, the AMOS III-70 will give the RVR in miles and in increments of 1/10 mile. The AMOS III-70 capability of displaying visibility information does not allow a direct use of RVR measured simultaneously by various transmissometers located along the runway unless the information supplied by the different transmissometers can be sequentially displayed. If this choice is selected the readout will reduce the ability of the controller to assess the variability of RVR along the runway. At present it is planned that the visibility input of the AMOS will be in parallel with the panel meter of the RVR computer.

At the Aircraft Cockpit. At the present time there is no plan to supply the cockpit directly with the information given by the AMOS-III-70.

PROPOSED VISIBILITY INFORMATION FLOW IN THE AIRPORT-AIRCRAFT SYSTEM

The optimum presentation of visibility information to the air traffic controller and the pilot is a complex problem. All future available visibility information would burden the controller and the pilot to a point of diminishing returns. It is clear that due to the nature of the visibility information (RVR, SVR) it is not obvious how to "package" it in a simple form from which the user can compose a simple description of the visibility situation. It is evident that any choice in the amount of visibility information and its readout and presentation has to be followed by a series of experiments and operational evaluations, especially during CAT II and III conditions, in order to improve it to the point of being useful and operationally acceptable by the pilots and controllers.

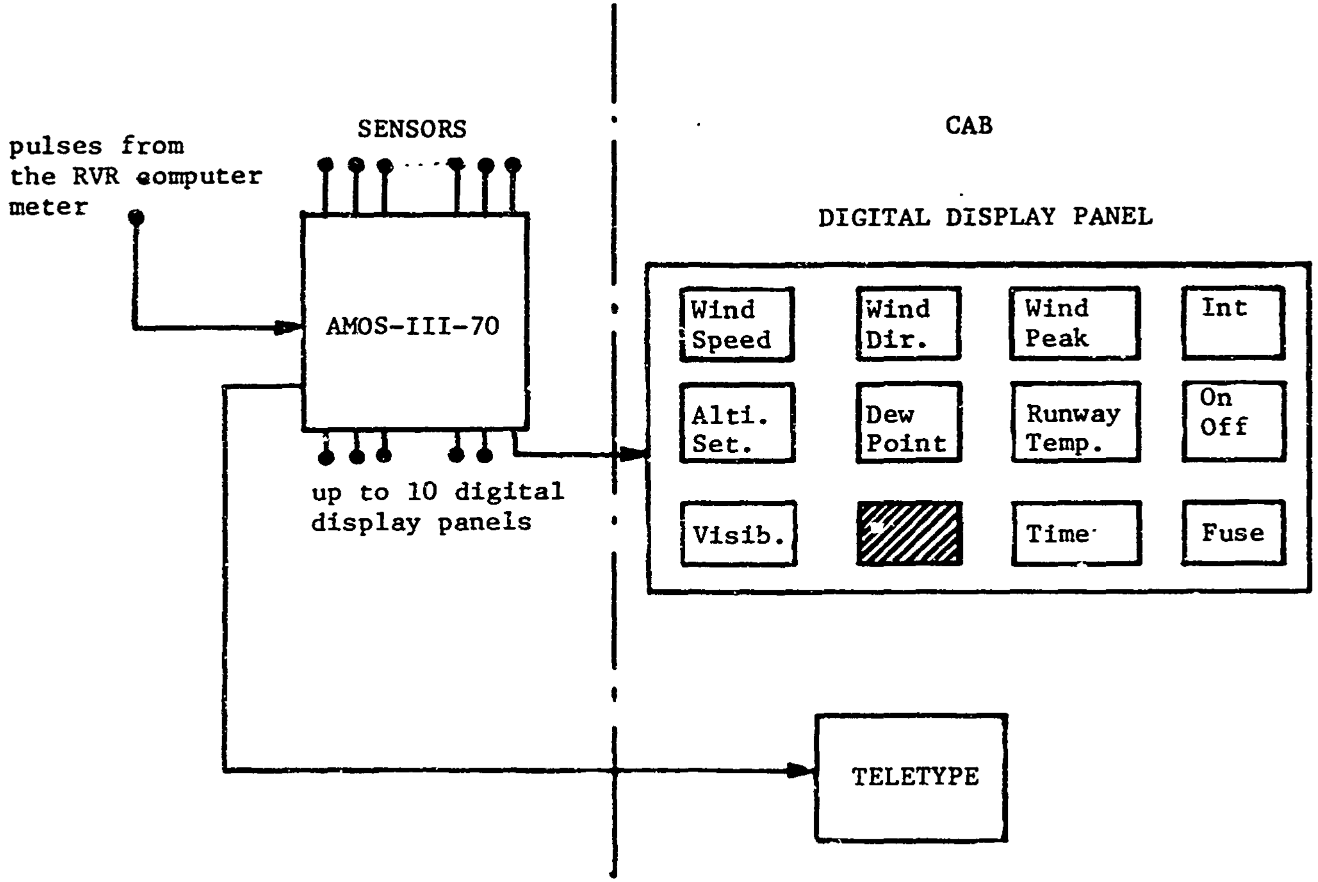


Figure 9. Block Diagram Showing the Proposed AMOS III-70 Remote Digital Display Panel in the CAB.

Under the present circumstances, there is a lack of a clear definition of the visibility information operational needs. We will propose a "middle of the road" visibility information flow that could be easily "adjusted" at a later date.

In our example main airports will have three instrumented runways with a configuration as indicated in Figure 10. This configuration encompasses nine transmissometers for RVR measurements, six devices to measure SVR and one ceilometer. Figure 11 shows the block diagram for the proposed visibility information flow in an Airport-Aircraft System. All the transmissometers will be readout by one scanner through the proper interface. The readout will be sequentially fed to the RVR computer. To the same computer will be fed the atmospheric background illuminance, ground illuminance, High Intensity Runway Light setting and Approach Runway Light setting.

With this information the RVR computer will give the respective RVR values. Simultaneously, six SVR devices will provide information to the SVR computer via the proper interface and the scanner.

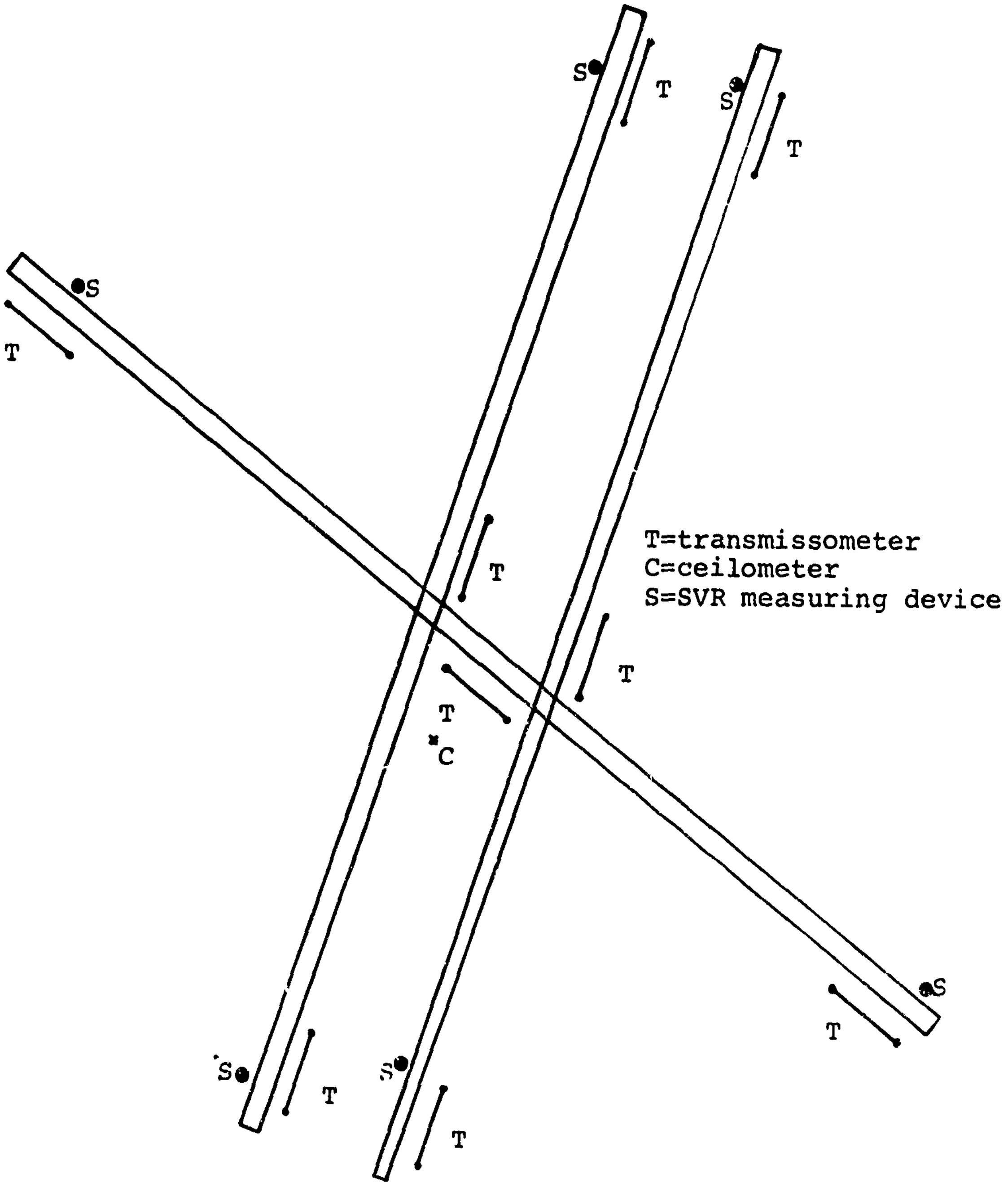
The RVR, SVR and ceilometer information will be sent to the Central Processor. This unit will perform all the preprogrammed decisions and computations based on RVR, SVR and ceilometer data. In addition, it will handle failure signals from different parts of the visibility measuring system. On the basis of the computations and decisions by the processor the following visibility information is supplied to the Control Tower:

- Runway Visual Range:
  - Touchdown
  - Midpoint
  - Rollout

- Slant Visual Range

- Ceiling

This information will be supplied to the CAB for the runway and direction selected by the controller. Photometric information is also supplied to the CAB via the Central Processor. This information consists of the setting of the HIL and approach lights, and the status of the sequenced flashing lights (on or off). The Central Processor will also supply the CAB with visual and audio signals when a failure occurs in the visibility system, or a change in visibility category takes place for the selected runway. Prerecorded messages that will automatically be sent to the pilot when a failure in the visibility system occurs will also be fed to the Central Processor.



T=transmissometer
C=ceilometer
S=SVR measuring device

Figure 10. Assumed Instrumented Runways Configuration.

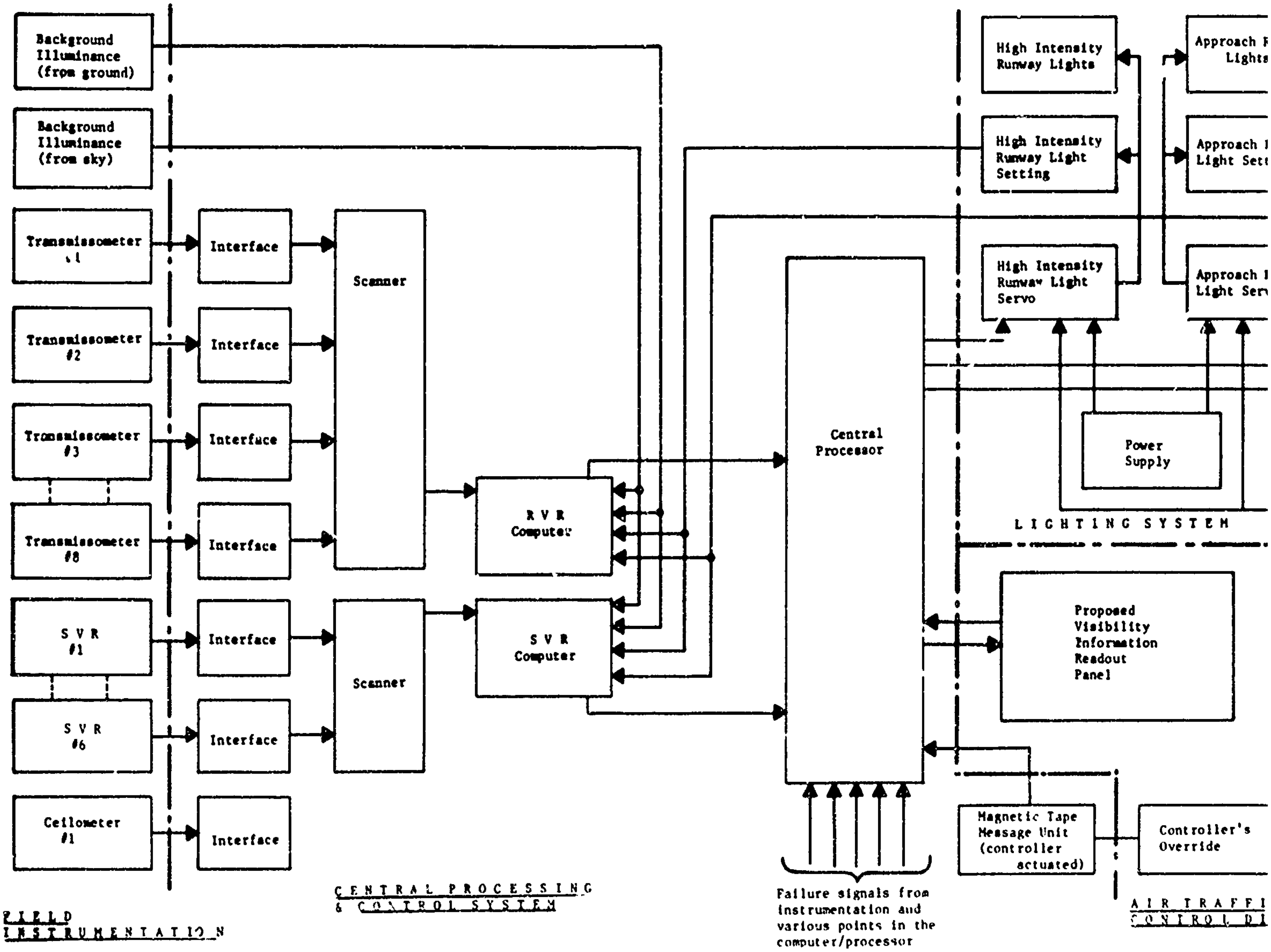
It is proposed that the visibility information and prerecorded messages be fed through the proper interface to a given communication or data link between the ground and the aircraft. This means that the visibility information should be supplied to the pilot automatically without the intervention of the controllers.

The prevailing visibility, as measured visually by an observer, will be "dialed in" by the ground controller and automatically fed to the Central Processor.

At present there are several systems being considered for transmitting data to aircraft. At the second meeting of the Automated Data Interchange Systems Panel (ICAO)(1) it was suggested that a "middle of the road" Mobile Digital Communication System should include a Terminal Weather Message with the following content:

(A) Altimeter setting
(B) Runway conditions
(C) Runway temperature
(D) Runway visual range
    touchdown
    mid-point
    roll out.
(E) Sky condition
(F) Turbulence
(G) Wind direction and speed (surface)
(H) Status of navigational aids
(I) Etc

It will be noted that Runway Visual Range (D) is included. This possibility is indicated in Figure 11 as Ground-to-Air Data Link. A proposed "New Guidance System for Approach and Landing"(9) also includes a provision to transmit RVR (4 bits). In this proposal it is stated that "Environmental information of a meteorological nature (RVR, touchdown-zone wind, and available wind-shear data) may be of a rapidly changing nature. While it is desirable that this information also be transmitted in direct association with the guidance signal (if auxiliary data capacity permits), it can be considered a trade-off item, and can be transmitted otherwise on a separate ground-air data link." Such a system might be the one mentioned above.


Background Illuminance (from ground)
Background Illuminance (from sky)
Transmissometer #1
Transmissometer #2
Transmissometer #3
Transmissometer #8
S V R #1
S V R #6
Ceilometer #1
Interface
Interface
Interface
Interface
Interface
Interface
Interface
Scanner
Scanner
R V R Computer
S V R Computer
Central Processor
Failure signals from instrumentation and various points in the computer/processor
High Intensity Runway Lights
High Intensity Runway Light Setting
High Intensity Runway Light Servo
Approach
Lights
Approach
Light Sett
Approach
Light Serv
Power Supply
LIGHTING SYSTEM
Proposed Visibility Information Readout Panel
Magnetic Tape Message Unit (controller actuated)
Controller's Override
FIELD INSTRUMENTATION
CENTRAL PROCESSING & CONTROL SYSTEM
AIR TRAFFI
CONTROL DI

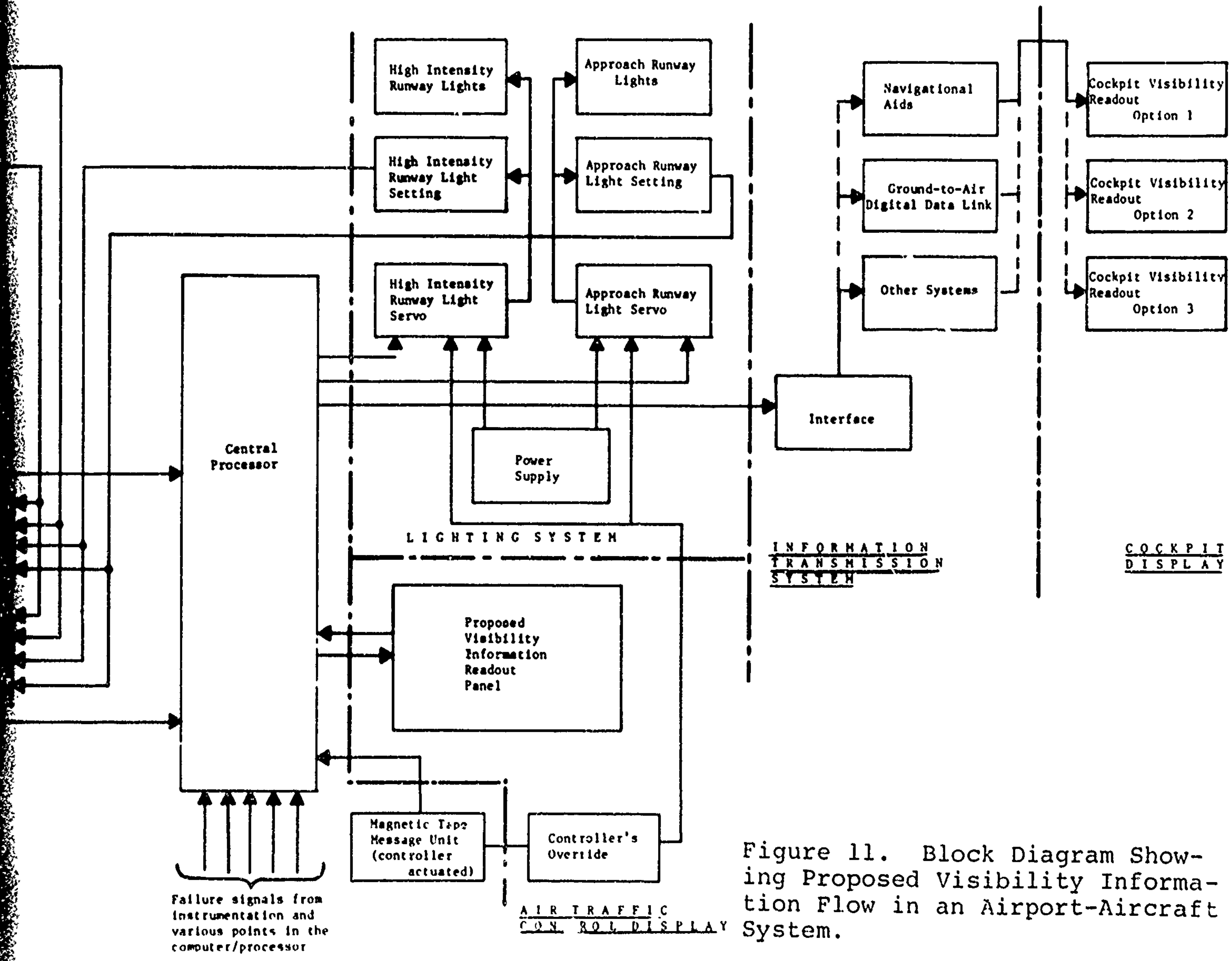


Figure 11. Block Diagram Showing Proposed Visibility Information Flow in an Airport-Aircraft System.

PROPOSED VISIBILITY INFORMATION AND READOUT AT THE TRAFFIC CONTROL TOWER

Based on considerations discussed in this report and on discussions with controllers and FAA personnel responsible for operations we conclude that the following types of information should be made available to the traffic controller in order to meet all present and near future visibility information requirements.

1) Runway designation (selected by the controller)
2) RVR at touchdown
3) RVR at midpoint
4) RVR at rollout
5) SVR
6) Ceiling
7) Prevailing Visibility (dialed in by the controller)
8) Light Settings for High Intensity, Approach and Sequenced Flashing
9) Indication to show the controller that any or all visibility information displayed in the panel is available to the pilot (cockpit) through the communication channel.

Taxiway Visual Range is excluded from this report due to the lack of an operational definition. We consider a typical airport with three instrumented runways two of which are parallel (see Figure 10).

Figure 12 gives the layout of the proposed Visibility Information Panel at the Traffic Control Tower. The proposed panel can be used as follows. The controller pushes the button to select the given instrumented runway and the selected direction. Figure 12 shows an arrangement to provide four instrumented runways, left and right and the designation of the selected runway. When the runway is selected, RVR values for landing, touchdown, midpoint, and rollout pertaining to that runway will appear automatically in the proper sequence. In the event that the controller chooses another runway or direction, the

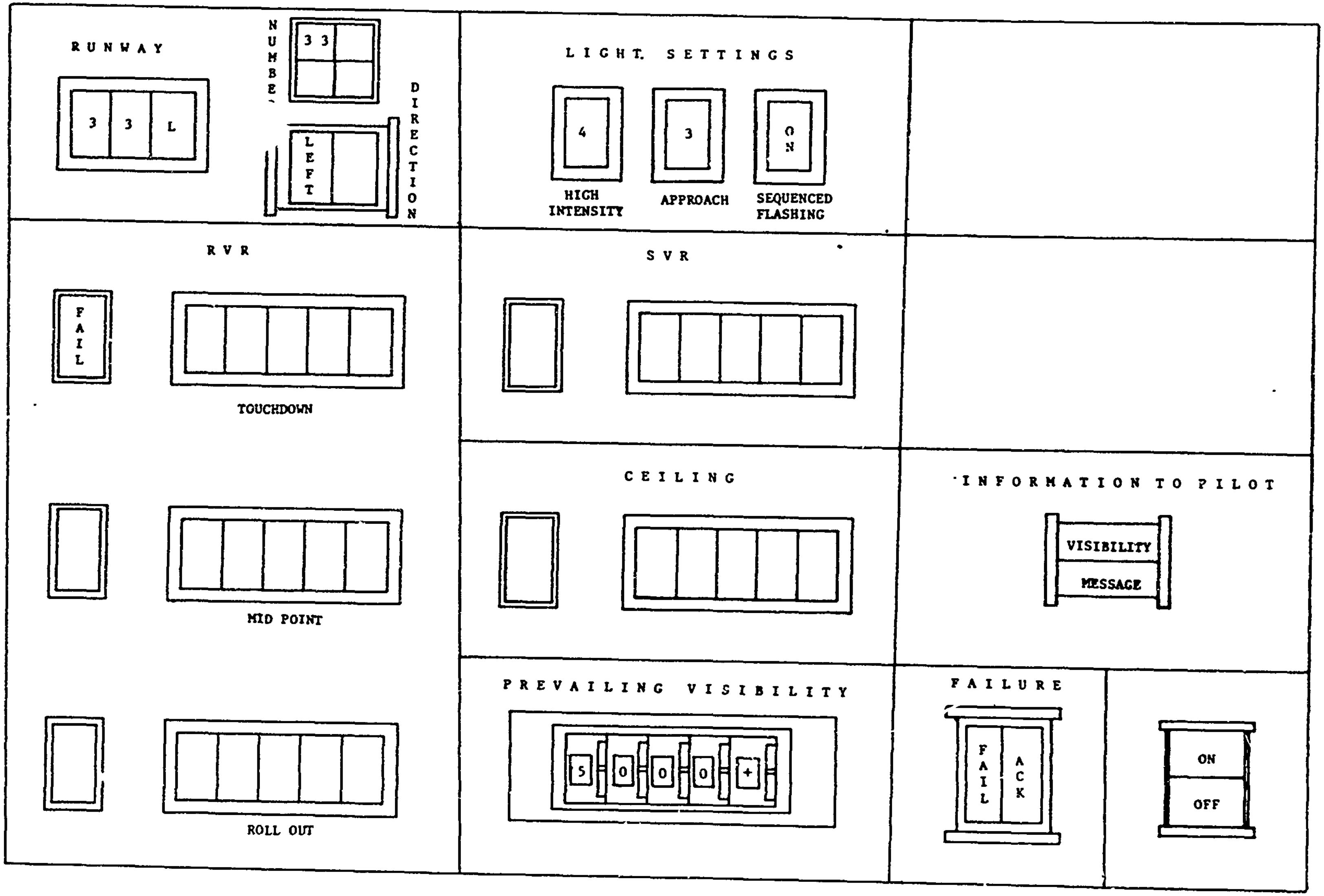


Figure 12. Layout of the Proposed Visibility Information Panel at the Traffic Control Tower.

RVR information will appear in the proper sequence. In the event that the fail safe of the visibility information system is triggered by a failure in any one of the RVR transmissometers, a red FAILURE sign will light on the left side of the particular RVR readout which failed. Otherwise a green light will indicate that everything is operating properly. On the basis of the RVR information and on the criteria established by ICAO, the visibility category will be displayed. Also when a change in category takes place and this change is maintained for a given period of time, it will be displayed with a flashing light and an audible alarm will notify the controller. The controller can push a lighted switch button that will turn off the flashing light and the sound alarm. This will be considered an acknowledgement on the part of the controller that a significant change took place.

There are two other locations in the panel to display future SVR and ceiling information. The ceiling readout could be eliminated from the panel if necessary; however, ceiling information provides a much better interpretation of the SVR reading. In cases that require prevailing visibility, there is a read-in counter that can be set by controller for the given prevailing visibility. This in turn will be relayed by means of an electrical readout to the system that will transmit visibility information to the pilot.

In the upper right part of the panel, there are four readouts for the high intensity light setting, approach light setting and an indication if the sequence flashing lights are on or off. We expect that the light settings of the high intensity and approach lights will be automatically set by the background illuminance with the possibility of override by the controller to adjust to particular conditions or to the request of the pilots.

It should be pointed out that the proposed Visibility Information Panel at the CAB accomodates the visibility information pertaining to one runway at a time. The controller will select the runway from which he requires the visibility information. In the case of simultaneous operation of dual runways another visibility information panel should be added at the CAB to allow for this type of operation.

PROPOSED VISIBILITY INFORMATION AND READOUT AT THE COCKPIT DURING LANDING

The kind of visibility information that we suggest should be supplied to the cockpit is based on the considerations made in the previous sections of this report, recommendations of ICAO and discussions between TSC personnel, cockpit designers, pilots, human factors engineers and operational personnel. To substantiate our recommendations we will identify the sources of information.

The criteria for visibility information display in the cockpit are based on the requirements during the approach and landing. In the following discussion, it is assumed that the pilot has received visibility information in the block of terminal information supplied by ATIS or any other system that might supercede ATIS in the future. It is also assumed that in general the pilot has at least a coarse estimate of the visibility on the runway, but not enough information for a good forecast of his ability to see at decision height, particularly in CAT II, IIIA and IIIB. Therefore at a certain point in the descent, information which contains the degree of variability should be supplied to the pilot. When we mention variability, the following question arises: On what time scale? According to the FAA, the decision height is the height at which the pilot must assess the landing situation and decide whether he will have sufficient visual access to the runway to procede with the landing maneuver. Table 2 shows that for a commercial jet aircraft the decision height occurs approximately 12 seconds away from touchdown. It is reasonable to suppose that the visibility information that the pilot receives should indicate that the visibility is sufficiently stable and is representative of the conditions at touchdown. RVR information should therefore be updated approximately every 12 seconds, although this number must ultimately be based on experiment and operational experience.

The regularly updated visibility information should be made available to the pilot starting approximately at the outer marker or 2.5 minutes before he reaches the inner marker (decision height). This information should be presented to the pilot so that he can picture the visibility conditions to be expected during landing. In our considerations, we have assumed that ceiling and SVR can both be measured and are sent to the pilot as the first pieces of information that he needs. Next will come the RVR, measured at touchdown, midpoint and rollout. These three RVR measurements give a description of the visibility along the runway. Conversations with pilots* and human factors engineers* indicate that the clearer the pilot's idea is of the existing visual conditions along the runway, the better will be his reactions. As an example, consider a fog bank which is covering a fifth of the runway. On entering the fog, the pilot who has expected the condition and is also aware of the extent of the fog along the runway will be able to react with greater confidence than a pilot unaware of the total runway visibility distribution.

*H. C. Ingrao meeting at McDonnell-Douglas Science Research Directorate (Long Beach, California), January 13, 1971 with members of the McDonnell-Douglas staff.

Two recommendations about RVR made by ICAO are relevant to the readout at the Traffic Control Tower and cockpit:

1) RVR should be reported at a rate of between once per second and once per minute.

2) Independent RVR reports should come from different parts of the runway.

The two general recommendations above are made independently and more specifically in our recommendations: An updating of RVR every 12 seconds and the use of three RVR measuring sites per runway. We should point out that the same updating rate (approximately 12 seconds) is reasonable for SVR.

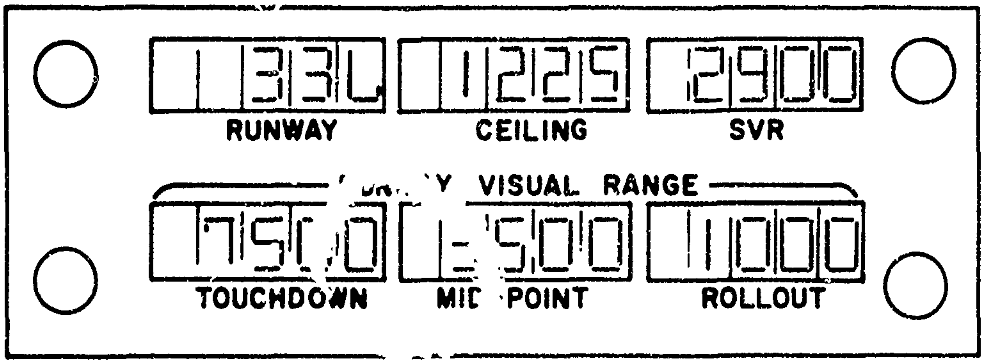
As indicated in the block diagram of Figure 11, the information transmission system could be one of the several that exist today or which are in the planning stage.

The type of cockpit displays can be classified as one of the following:

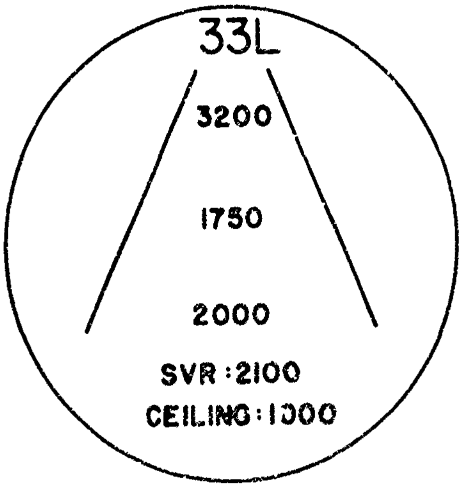
a) Continuous (analog)
b) Digital
c) Symbolic
d) Pictorial
e) Direct motion

The displays can also be grouped, depending on the type and function, into head-up and head-down displays. Head-up displays are those that the pilot can use while keeping his attention focused on the view outside the cockpit. Thus, the pilot can view a given head-up display while at the same time looking through the windshield.

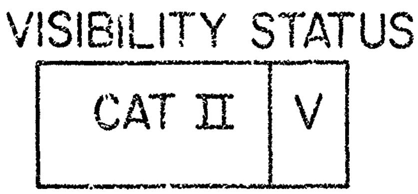
The choice of a given cockpit display for visibility information depends on many factors. In general these factors can be identified as "total concept" and man-machine compatibility. Therefore, we propose three alternatives for displays. The first, a head-down digital display, is depicted in Figure 13 (a). It consists of a labeled panel providing for readout of six pieces of information: Runway identification, ceiling, SVR, and three RVR values at touchdown, midpoint and rollout, respectively, in the order the pilot will need them. The pilot would have the same visibility information available to



(a) Conventional Aircraft Panel Digital Edge Lighted Head-Down Display



(b) Head-Up Display Panel Giving Same Information as (a) in a Modified Format



(c) Simplified Head-Down Display Giving Visibility Category

Figure 13. Layout of the Proposed Visibility Information Readout Panels at the Cockpit

him that the controller has and could make independent decisions with regard to approach and landing.

The digits would be formed with dotted matrix emitting diodes (provided that higher brightness levels could be obtained) and the panel would have variable edge lighting. The entire panel could be left normally blacked out and activated by the pilot pushing a button. In this way, the visibility data would not impose on the pilot's field-of-view except when he so chooses. In this sense, this option resembles the "on-demand" type of display.

The second display alternative, a head-up digital display, is shown schematically in Figure 13(b). This form of readout could in principal have the same information format as the head-down display discussed above. However, the unique appeal of head-up displays is the fact that information can be seen at the same time that the pilot is searching for visual cues. For this reason we have selected a display in which the RVR is digitally indicated at appropriate locations along a (fixed) perspective view of the runway. In this way, the pilot need not undergo an intermediate mental process of identifying the meaning of labels.

It will be noted that the information shown in Figure 13(b) is displayed on the face of a CRT. This choice was made for the following reasons. A CRT display is extremely flexible and allows alteration of format at will. This means that changes in display format, either due to new regulations or experience, can be introduced easily. Obviously, any format that is used in another display mode can also be used on the CRT. Furthermore a large amount of information is potentially available to the pilot, since the flexibility allows many kinds of data to be presented simultaneously or sequentially.

An efficient use of the CRT head-up display is to combine it with an on-board computer. The pilot would then have available to him at the push of a button (or many buttons) the information stored in the computer. The input to the computer would be relayed from the ground and updated at the specified rate. This computer could be either general purpose, of the type envisioned in the future or special purpose.

Finally, the third alternative is shown in Figure 13(c). Here the symbols are actually alphanumerics which indicate the visibility category and the degree of variability in the visibility status. The latter is indicated by showing a "V" in the right hand block when the conditions are sufficiently variable to be of operational concern. Another method to convey this information would be to flash the entire left hand block under variable conditions. The distinctive feature of this display is that the pilot has available a maximum amount of information with a minimum amount of display. The display is simple, small and inexpensive. Under many landing conditions such information is adequate. It is expected that the landing operations of the future will be reliably achieved by automatic means. Nevertheless the pilot will be responsible for the safety of the aircraft and will require a display system that will enable him to monitor the operation and act if necessary. Due to the low decision height, problems of eye accommodation, etc., it seems that the visibility information should be displayed in head-up fashion (e.g., Figure 13(b)) for CAT III operations.

PROPOSED VISIBILITY INFORMATION AND READOUT AT THE COCKPIT DURING DEPARTURE

The departure information and the criteria to deny take-off by the ground controller is well described in page 16 of this report. This information is supplied by the ground controller to the pilot via voice link.

It seems that until such time as advances in automatic cockpit display and information content therein are made, the ground controller will continue to maintain departure control as a function of currently defined RVR criteria and will therefore implement this control to the pilot via a voice radio link.

LIST OF REFERENCES

1. "Automated Data Interchange Systems (ADIS) Panel" Report Second Meeting Montreal 27 April - 15 May 1970.

2. Jackson, W. E., "The Federal Airways System", published by the IEEE, Inc., 1970.

3. Douglas, C. A., Young, L. L., "Development of a Transmissometer for Determining Visual Range", National Bureau of Standards, Report 47, February 1945.

4. "Preliminary Instruction Book, Runway Visual Range (RVR) System, Vol. I", July 1967, Prepared for the FAA, Contract FA6WA-1827 by Solid Radiations Inc., Los Angeles, California.

5. "Terminal Air Traffic Control", Department of Transportation, Federal Aviation Administration, Air Traffic Service. Document No. 7110.8B, April 1, 1971.

6. Beck, R. H., "The Hostile Environment of Low Visibility" Airlines Pilot Association, 15th Air Safety Forum, Seattle, Washington, July 9-11, 1968.

7. Kayton, M. and Fried, W. (Editors), "Avionics Navigation Systems", John Wiley and Sons, Inc., 1969.

8. Hexler, P. L. and Waters, R. H., "The AMOS III-70 Automatic Meteorological Observing Station", Bulletin American Meteorological Society, Vol. 49, No. 9, September 1968.

9. "A New Guidance System for Approach and Landing" Vol. One. Radio Technical Commission for Aeronautics. Document No. DO-148, December 18, 1970.