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VISUAL CONFIRMATION (VICON) SYSTEM RELIABILITY ANALYSIS

WIND SHEAR SYSTEMS INTEGRATION PLAN, TASK D-1

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February 1980

Task Report

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16. Abstract

This study supports the system reliability area of the VICON Operational Evaluation Program. VICON is the FAA's VIsual CONfirmation system which visually confirms that an aircraft awaiting takeoff has been verbally cleared for takeoff by the airport controller. Specific objectives of the study are:

- Evaluate system failure modes and identify critical system components.
- Evaluate the need for concept or design modifications needed to support reliability objectives for the production system.
- Provide inputs to the VICON maintenance and spares recommendations.
- Determine the sensitivity of system reliability/availability values to design and spare parts options.

It is found that the predicted availability of the VICON system as installed at Bradley International Airport is 99.94% for the seven month test period. It is also found that the number of spare parts to provide a 99% assurance that there will be no degradation of VICON system performance due to a lack of spare parts over 6 months is predicted to be sixty-three total spares covering twenty-seven different component types. Thirty percent of the spares are required for the controller's operating switches.

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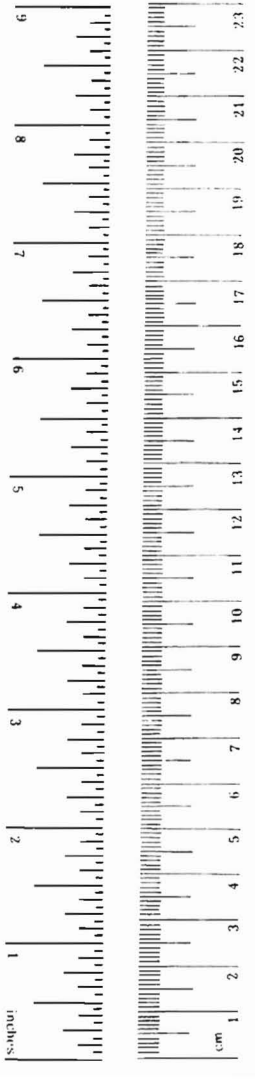
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exact). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

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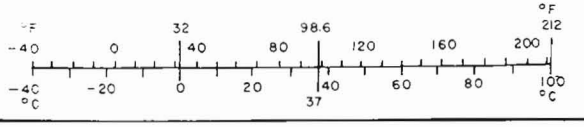
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. INTRODUCTION

A. Background

The VICON system is a visual backup for the air traffic controller to confirm his/her vocal clearance to pilots waiting to take off and to prevent any possible misunderstanding of the controller's instructions.

VICON was developed primarily to avoid catastrophes such as the 1977 runway collision of two Boeing 747s at Tenerife Island in which over 550 persons were killed.

VICON consists of clusters of three, pulsing, green lights located at takeoff positions along the left side of runways. The lights are mounted on 14-inch-high frangible tubes, and one or more of the lights will always be visible to pilots of aircraft on taxiways or runways.

After giving voice clearance to an awaiting aircraft, the controller pushes a button which activates the appropriate VICON lights. When the pilot sees these lights, visual confirmation is complete. The VICON lights will then be turned off automatically when the aircraft breaks an electronic beam across the runway or by a timing device. The timing device would be adjusted according to airport traffic conditions.

The initial development testing of the VICON system was done at the NAFEC/Atlantic City Airport. The operational evaluation is being conducted at Bradley International by NAFEC in support of the FAA's Air Traffic Service.

The operational evaluation is intended to accomplish the following:

1) Determine pilot and controller reactions to the VICON concept and its implementation.

2) Evaluate design alternatives.

3) Assess system reliability.

4) Provide cost data for various configurations.

5) Evaluate system installation problems.

This study is in support of the system reliability area of the Operational Evaluation Program.

B. Study Objectives

The overall objectives of this study are twofold, i.e. 1) to provide reliability inputs to support system trade-offs studies and 2) to provide reliability recommendations for the VICON Technical Data Package (TDP).

A TDP is required for each R&D program which is intended for inclusion in the F&E program. The reliability inputs to VICON TDP are particularly important since certain failure modes of the system could impact safety.

Specific objectives to be addressed in this study are as follows:

- Evaluate system failure modes and identify critical system components.
- Evaluate the need for concept or design modifications needed to support reliability objectives for the production system.
- Provide inputs to the VICON maintenance and spares recommendations.
- Determine the sensitvity of system reliability/availability values to design and spare parts options.

II. SUMMARY

A. Definition of System Failure

In order to define system failure, it is first necessary to establish a precise statement of the mission of the VICON system. While the ultimate mission of VICON is to confirm voice takeoff clearances to the pilot, the primary mission of the Bradley installation is the collection of data on pilot and controller reactions to VICON and on the suitability of the hardware design under actual field conditions. Furthermore, it is intended that the VICON tests conducted at Bradley will place a minimum of additional burden on tower personnel.

The system failure definition is based on the concept of minimizing the burden to tower personnel in remembering which runways have VICON capability and which do not without being overly restrictive to the point where loss of a relatively small portion of the system places the entire system out of operation. The definition for this study is:

SYSTEM FAILURE

> The VICON system is failed whenever two or more runways are failed, except in the case when exactly two runways are failed there is no failure if the runways are reciprocal.

This study also evaluated a secondary level of failure, i.e., runway failure. In this case, the failure definition is based on the anticipated takeoff utilization at Bradley International; i.e., the majority of total takeoff operations will occur from the ends of the runways. However, the majority of the General Aviation takeoffs will be from runway intersections.

The definition for this study is:

RUNWAY FAILURE

> VICON is failed on a given runway whenever VICON clearances cannot be given to 15% or more of the anticipated departures for the total runway or whenever 50% or more of the VICON lamp clusters are out of service regardless of the percentage of departures effected.

This means that loss of the end lamp cluster or loss of one half or more of all lamp clusters is defined as a failure for VICON for any given runway.

B. Predicted Vicon Reliability/Availability

The predicted availability of the VICON system as installed at Bradley is 99.94% which means that the Bradley VICON can be expected to be capable of performing its defined mission of data collection during 99.94% of the seven month test period. Based on a total 4032 hours of data collection time during the test period, VICON can be expected to be operational during all but two (2) hours. The lack of VICON during this two (2) hour period will result in loss of only 0.31% of the total takeoff data points expected to be available during the test period.

The reliability of the VICON system has no bearing on its ability to perform the defined data collection mission; however, it can be noted that the Bradley VICON installation has a minimum reliability of 99.998% with respect to the granting of any single VICON clearance. In other words, a VICON clearance can be expected to be interrupted by equipment failure once in every 100,000 clearances or once every 30 months at Bradley International.

None of the components of the Bradley VICON System have predicated availability values that are excessively low; however, in the case of component reliability, the lamp clusters have a predicted reliability that is an order of magnitude less than the reliability of all other system components combined. This is a reflection of the high failure rate for the individual lamps that was provided by the lamp supplier. This failure rate is based on the aggregate behavior of the lamps in many applications, not necessarily similar to VICON usage. It is anticipated that the Bradley test will provide a more accurate estimate of lamp reliability in the VICON System environment to permit a final determination to be made as to whether or not a reliability problem exists.

C. Major Problems

The Bradley VICON System has eleven critical components. Failure of any one of these eleven components will result in failure of the entire system of 21 departure points, while failure of any of the remaining non-critical components will cause failure of a single departure point. Design changes have been recommended (Chapter IV) to eliminate all single points of failure. Implementation of these changes would increase the availability of the Bradley System from 99.94% to 99.99% with a negligible effect on single clearance reliability.

D. Sparing

The number of spare parts required to provide a 99% assurance that there will be no degradation of VICON system performance due to a lack of spares over a period of six (6) months, has been predicted. Sixty-three

total spares covering twenty-seven different component types are needed with approximately 30% of the spares being required for the controller's operating switches.

It is interesting to note that the runway lamps do not dominate the spare parts picture, despite the fact that the lamp failure rate is two orders of magnitude greater than the next largest component failure rate. The override switch, runway activation switches, microwave detectors, fuses for the 48 VDC supply and the departure activation switches are all spared at a higher level than the lamps.

This situation is a direct result of the definition of provisioning protection level as the probability of no system failure due to a stock outage. Consequently, the number of spares assigned to each component is a function of both component failure rate and the impact of component failure on system performance. The high failure rate of the lamps is essentially offset by the relatively minor impact on system performance of the failure of a lamp while the catastrophic system impact of the failure of components such as the override and activations switches results in these components being heavily spared even though they have lower failure rates.

The spares provisioning analysis presented here is essentially an example of the technique rather than an actual sparing recommendation since the spares complement given in Chapter IV is valid only for the VICON System configuration at Bradley. Installations at other locations or even modification to the Bradley System would necessitate a new analysis being made.

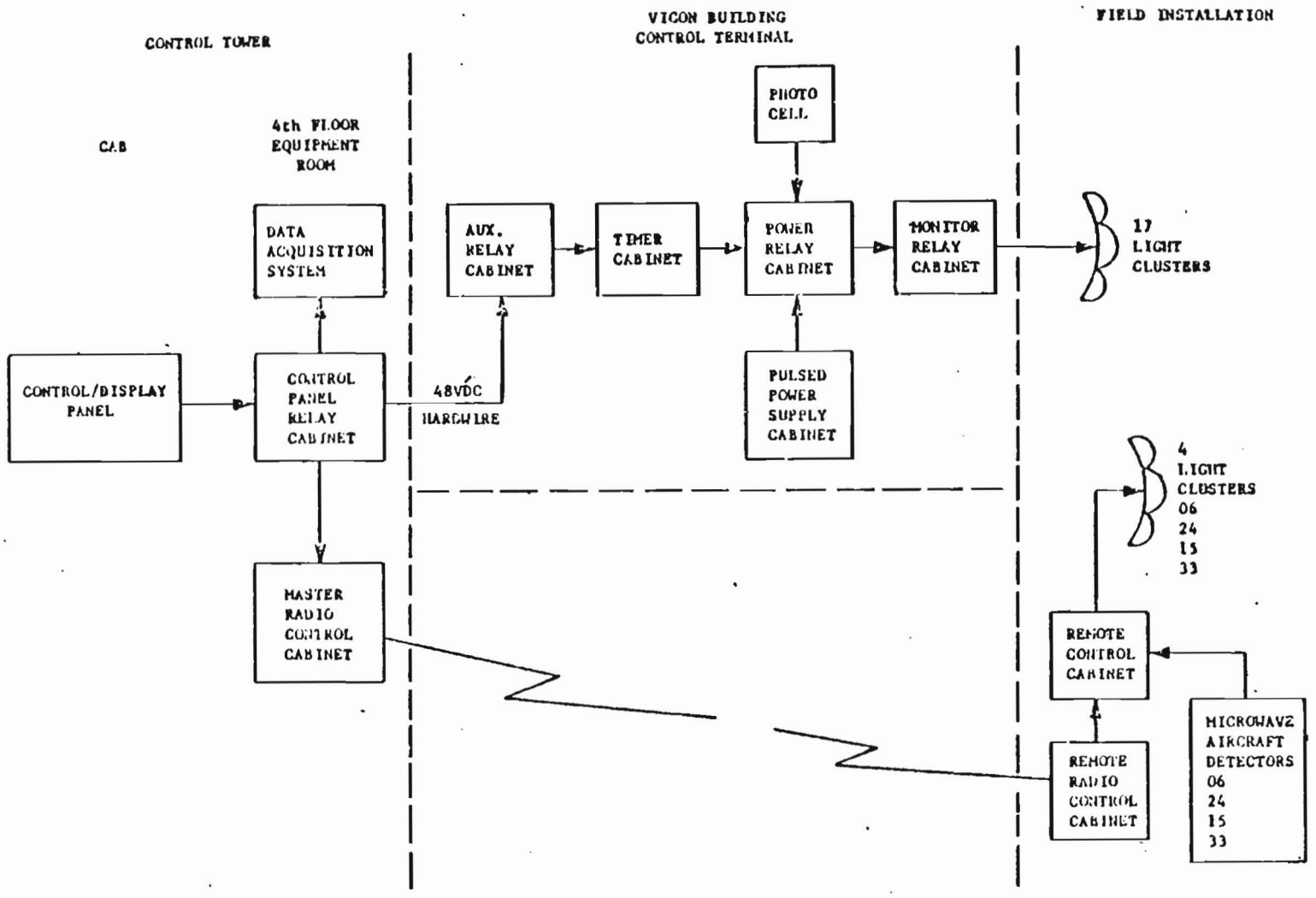
III. SYSTEM DESCRIPTION

A. Functional Description

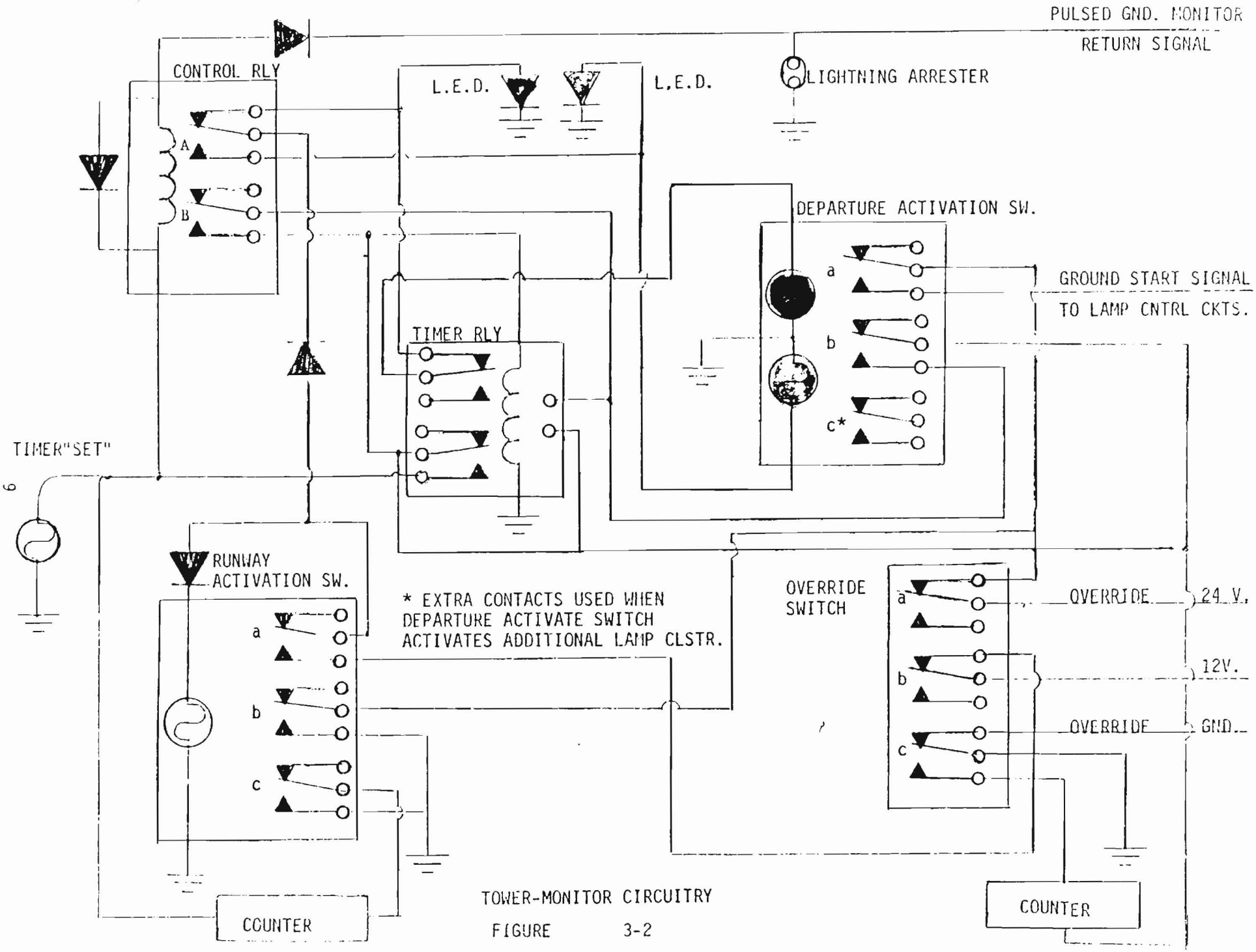
The VICON System, as installed at Bradley International Airport, consists of twenty one (21) lamp clusters located at runway takeoff positions and the control and monitoring devices necessary to ensure proper system operation.

As depicted in Figure 3-1, the VICON System can conveniently be thought of as consisting of three major component groups: (1) the operator control and monitoring equipment located in the control tower; (2) the lamp clusters located along the runways; and (3) the interconnecting circuits that transfer control and monitor signals between tower and lamps supply power to the lamps and provide for automatic lamp shut off following aircraft departure. The Bradley installation utilizes two type of interconnecting circuits: a hard-wire system and a radio-link system. Figures 3-2, 3-3, and 3-4 are simplified schematics of the operator control and monitoring equipment, the hard-wire interconnecting system and the radio-link interconnecting system. Figure 3-5 shows the lamp power circuitry.

Figure 3-2 shows the operation of a typical control and monitor circuit used by the controller to operate one of the VICON lamp clusters and to verify that operation has occurred. The sequence of events leading to the turn-on of a VICON lamp cluster begins with the operation of the runway activation switch for any of the six runways at Bradley. When actuated, the runway activation switch enables all of the departure activation switches associated with a particular runway by using contact set "b" to establish a ground on the moving element of contact set "a" of each depature activation switch. Operation of a runway activation switch also transmits 12VDC through contact set "a", to illuminate an amber indicator lamp

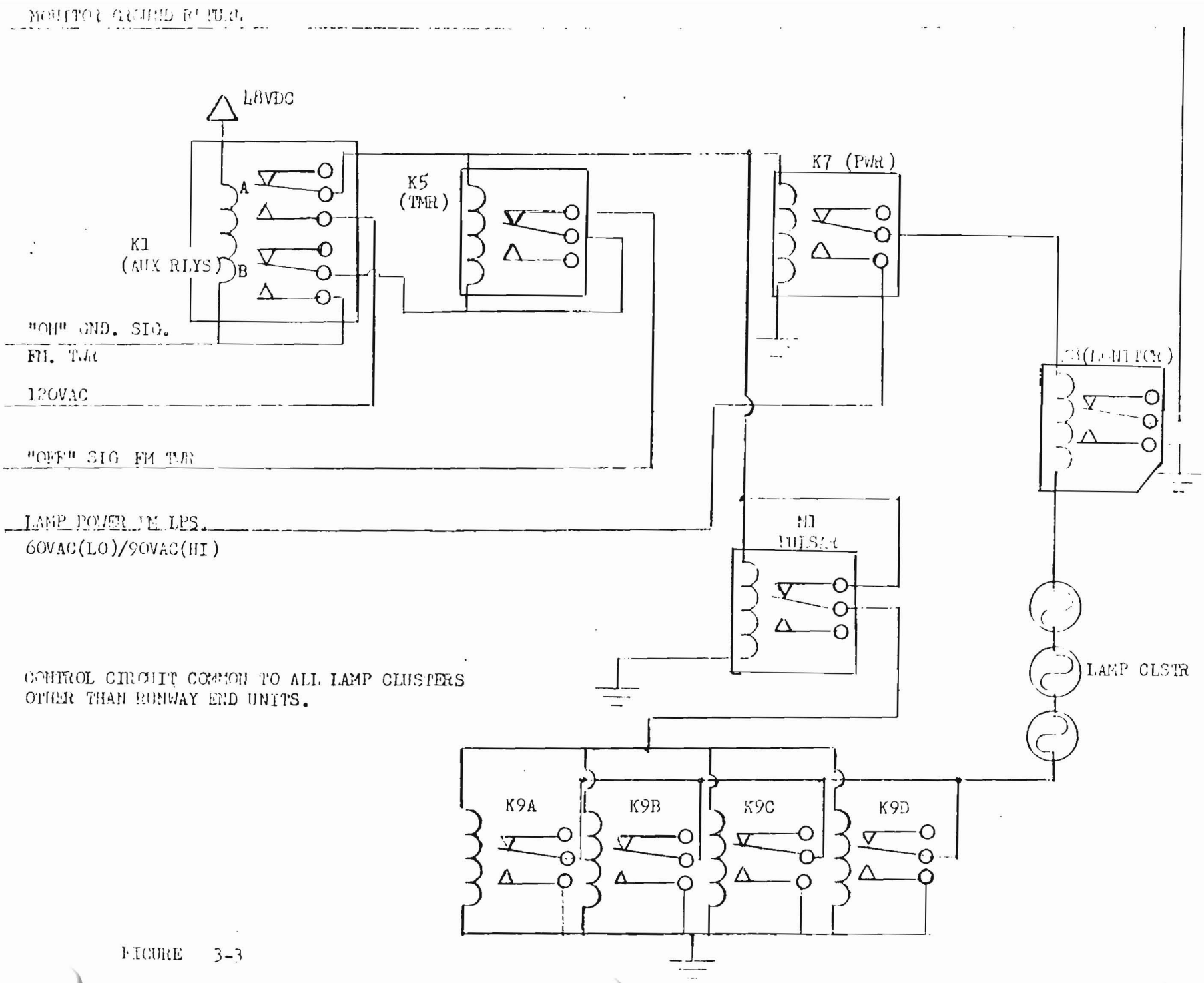


Block Diagram of VICON System
Figure 3-1



TOWER-MONITOR CIRCUITRY

FIGURE 3-2



CONTROL CIRCUIT COMMON TO ALL LAMP CLUSTERS OTHER THAN RUNWAY END UNITS.

FIGURE 3-3

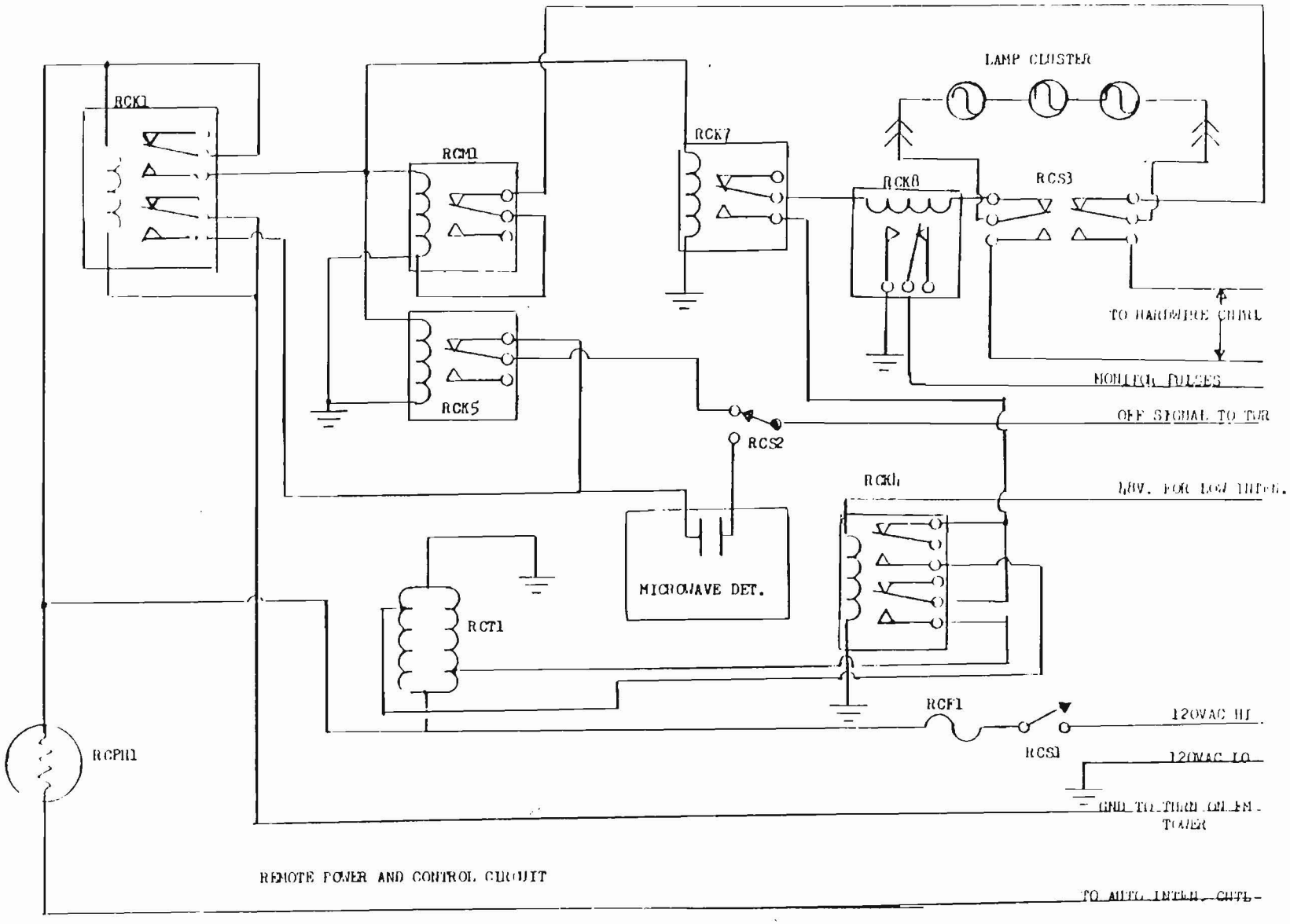
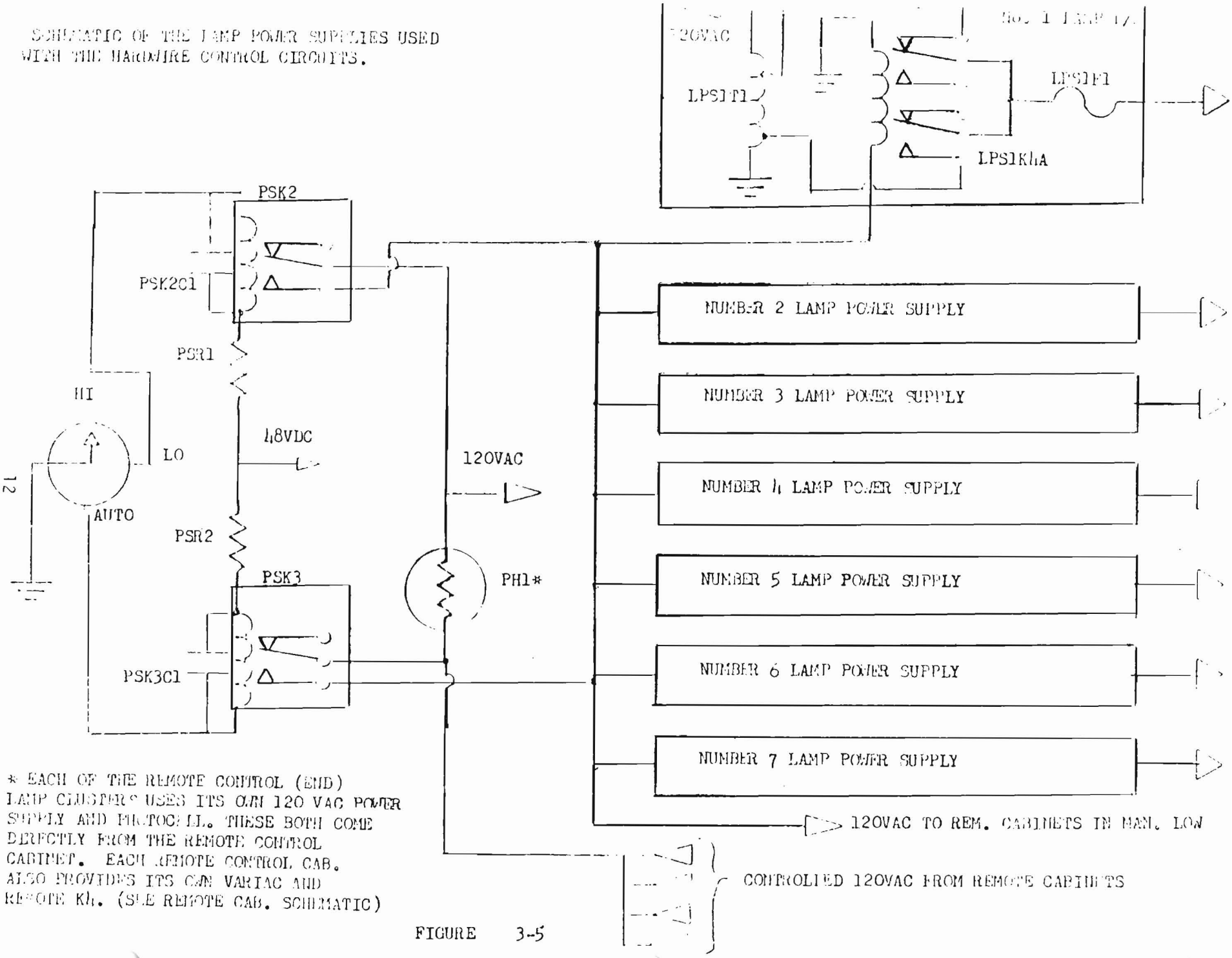

RCK1
RCM1
RCK5
RCK7
RCK8
RCS3
LAMP CLUSTER
TO HARDWIRE CNTRL
MONITOR PULSES
OFF SIGNAL TO T/R
RCS2
RCK4
48V. FOR LOW INTEN.
MICROWAVE DET.
RCT1
RCF1
120VAC HI
RCS1
120VAC LO
RCPH1
GND TO THRU GRLFM TOWER
REMOTE POWER AND CONTROL CIRCUIT
TO AUTO INTEN. CNTL.

FIGURE 3-4

SCHEMATIC OF THE LAMP POWER SUPPLIES USED WITH THE HARDWIRE CONTROL CIRCUITS.



* EACH OF THE REMOTE CONTROL (END) LAMP CLUSTERS USES ITS OWN 120 VAC POWER SUPPLY AND PHOTOCELL. THESE BOTH COME DIRECTLY FROM THE REMOTE CONTROL CABINET. EACH REMOTE CONTROL CAB. ALSO PROVIDES ITS OWN VARIAC AND REMOTE K4. (SEE REMOTE CAB. SCHEMATIC)

FIGURE 3-5

in the runway activation switch to provide a positive indication of the runway activated for VICON control. A set of lamps contained in the departure activate switches are illuminated to indicate the specific departure points along the runway at which VICON clearances may be given. A duplicate indicator panel is located in the equipment room to provide maintenance personnel with indications of runway and departure point status. Note that the 12VDC to the controller's indicators passes through contacts of both the control relay and the timer relay while the 12VDC to the equipment room indicators passes through the control relay contacts only. Finally, operation of a runway activation switch places a ground (through contact set "c") on a counter that is not a component of the VICON system but a part of the test installation at Bradley that is being used in the evaluation of VICON.

To illuminate any VICON Lamp cluster on a runway that has been activated for VICON, the controller operates the departure activation switch associated with the intended departure point, thereby sending a start signal (ground) to one (or two) lamp control circuits through contact set "a" (and "c"). Contact set "b" switches +24VDC to start the timer relay which immediately transfers both sets of contacts until the expiration of its timing period, when they are returned to the diagrammed position (see Figure 3-2). Transfer of timer contact set "a" interrupts the 12VDC supply and extinguishes the amber indicator lamp in the departure activation switch. Transfer of contact set "b" provides +24VDC to the control relay enabling it to respond to the monitor return signal (pulsating ground) from the lamp control circuits. The monitor return circuit supplies a succession

of ground pulses, corresponding to the pulsating operation of a lamp cluster, which results in the control relay being alternately energized and de-energized. The alternating operation of contact set "a" of the control relay causes the green indicator lamp in the associated departure activation switch to flash and also causes the yellow and green indicators in the equipment to light alternately. When the set time expires, the timer relay returns both set of contacts to the position shown in Figure 3-2, de-energizing the control relay and re-lighting the amber indicators in the departure activation switch and in the equipment room.

The turn-off of a VICON lamp cluster is normally accomplished automatically by the lamp control circuitry; however, the controller can exercise manual turnoff control by operating the override switch. Contact set "c" opens to interrupt ground to the lamp control circuits and turns off all lamp clusters. Contact set "a" and "b" interrupt the 24 VDC and 12 VDC lamp to darken all indicators as an indication of override operation.

Figure 3-3 shows the hard-wire control circuit used with all of the VICON lamp clusters installed at Bradley. The "ON" signal from the tower is a momentary ground that operates the appropriate auxillary relay (K1). The closing of contact set "B" of K1 establishes a holding circuit to ground through the closed contacts of timer (K5) and through normally closed contacts of the override switch in the tower. Operation of contact set "A" supplies 120VAC to the power relay (K7) and the pulser (M1). Operation of K7, in turn, supplies 60VAC/90VAC lamp power to the lamp cluster through the monitor relay (K8) coil. Pulser (M1) alternately opens and closes its contacts as long as it is energized. This operation of the pulser alternately

energizes and de-energizes the four parallel pulser relays K9A, B, C, D which in turn supply a pulsating ground to the lamp cluster causing the lamps to flash. This pulsating ground is also fed to the monitor relay (K8) whose contacts transmit a pulsating ground on the monitor return line to the tower. When the timer (K5) completes its cycle, the contacts open to de-energize the auxillary relay which in turn de-energizes the power relay and the pulsar to shut off the lights and the monitor return signal. Shut off can also be accomplished by the "off" signal transmitted manually from the tower which consists of interrupting the ground to the holding circuit of K1.

Figure 3-4 shows the lamp control circuit used with the radio link. The auxillary relay (RCK1), power relay (RCK7), timer (RCK5), pulser (RCM1) and monitor relay (RCK8) perform exactly the same functions as in the hard wire system. The differences between this system and the hardwire system are: (1) turn-on and manual turn-off signals are transmitted via radio rather than wire; (2) the pulser controls lamp ground directly instead of through a set of relays; (3) the timer (RCK5) can be switched out of the circuit, via RCS2, and replaced by the microwave detector which senses aircraft passage and opens the ground to RCK1 to shut off the lamps; and (4) it contains its own power supply. The power supply operation is the same as described for the hard wire system in the next paragraph. Note that lamp clusters with radio-link control can be switched to hardwire control through RCS3 if desired.

Figure 3-5 shows the lamp power supply associated with the hardwire lamp control systems. Note that the intensity switch shown here also controls the intensity of the power supplies used with the radio-link control systems. The power supply provides either one of two voltages to the lamp

clusters in accordance with the lamp intensity required by ambient light conditions. When the lamp intensity switch is set to HI, relays PSK2 and PSK3 have no connection to ground and are therefore de-energized so that relays LPS1K4A through LPS7K4A in the seven lamp power supplies are also de-energized and the high voltage output of the seven auto transformers (LPS1T1 through LPS7T1) are connected to the lamps. When the intensity switch is set to LO, relay PSK2 is activated which in turn energizes relays LPS1K4A through LPS7K4A to connect the lower voltage output of the auto transformers to the lamps. Placing the intensity switch in the Auto position de-energizes PSK2 and energizes PSK3 so that photo cell PH1 controls relays LPS1K4A through LPS7K4A and the voltage to the lamps.

B. Physical Description

Figure 3-6 shows the location of each of the twenty one (21) VICON lamp clusters at Bradley International Airport; the arrows at each cluster indicating the take off direction of aircraft controlled by the cluster. Clusters 18, 19, 20 and 21 have both radio link and hardwire control circuits while all others have only the hardwire control.

Each of the VICON locations has a cluster of three lamps,(see Figure 3-7), with one lamp parallel to the runway edge at 0° elevation, one lamp at 30° to the runway edge and 6° elevation and one lamp at 60° to the runway edge and 12° elevation.

The lamp control circuits, power supplies and radio equipment associated with locations 18, 19, 20 and 21 are mounted in weather proof cabinets adjacent to the runways near the lamp sites, with the photo cell that controls lamp intensity situated atop the lamp control enclosure. The microwave detector units (Figure 3-6), associated with location 18, 19, 20 and 21, are situated on either side of the runway so that during takeoff the aircraft will pass between the detectors.

The components of the hardwire lamp control circuitry are mounted in five (5) cabinets all housed within a single building, located at the site identified as ASR on Figure 3-6. Like components are mounted together in the same cabinet with all auxillary relays in one cabinet, all timer relays in another cabinet, the power relays together in the third cabinet, the monitor relays, pulsar and pulsar relays occupying the fourth cabinet and all power supply components residing in the fifth cabinet.

VISUAL CONFIRMATION OF VOICE TAKEOFF CLEARANCE

VICON

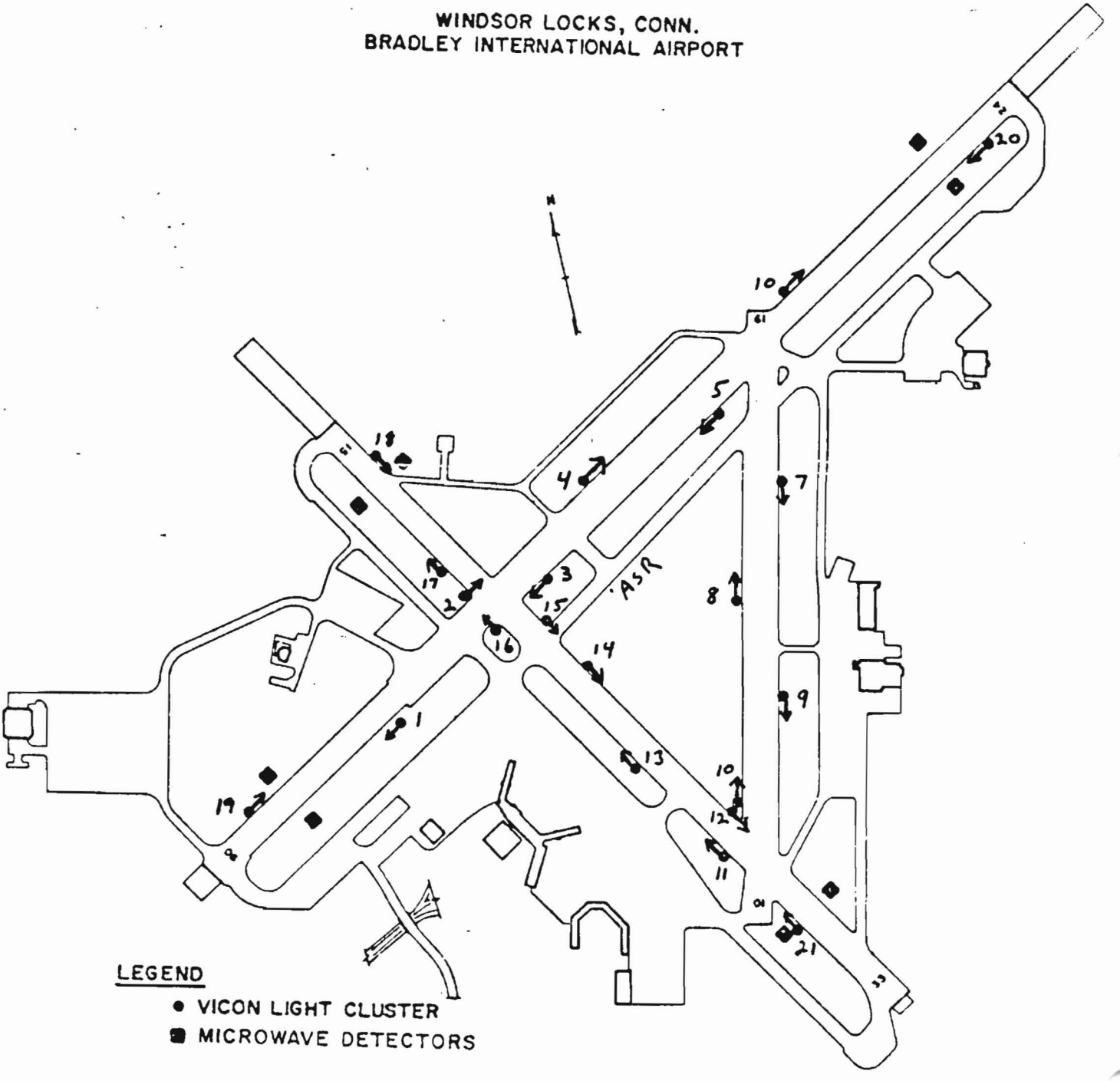


Figure 3-6

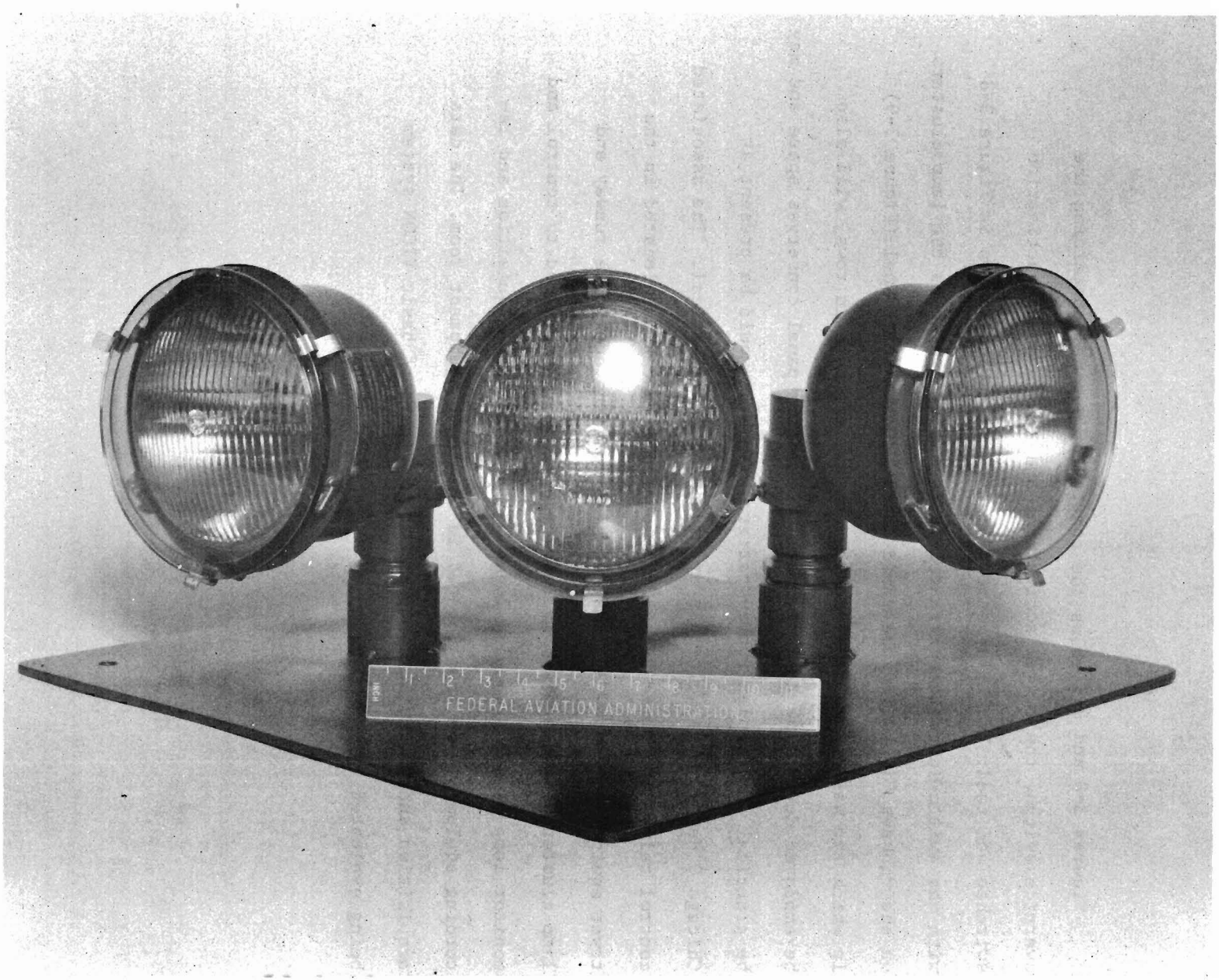


Figure 3-7. Light Cluster

Figures 3-8 and 3-9 shows the controller's panel containing the override switch, the runway activation, and the departure activation switches and their built-in monitor lights. The panel shown in Figure 3-8 with the switch/indicators arranged in the same pattern as the lamp clusters on the runways, is called the mimic panel. The matrix panel (Figure 3-9) in which the various switches/indicators are arranged in rows, will also be employed during the test program. The matrix panel conserves space and may be practical for complex runway patterns, such as would be present at Chicago O'Hare. The two panels are functionally identical. The associated control relays and timer relays are mounted in a cabinet located in the tower equipment room. This cabinet also contains duplicate runway and lamp cluster status indicators. The master radio unit used to control and monitor lamp clusters 18, 19, 20 and 21 and the data acquisition and recording equipment are also located in the tower equipment room. The data acquisition and recording equipment are not part of basic VICON system being evaluated.

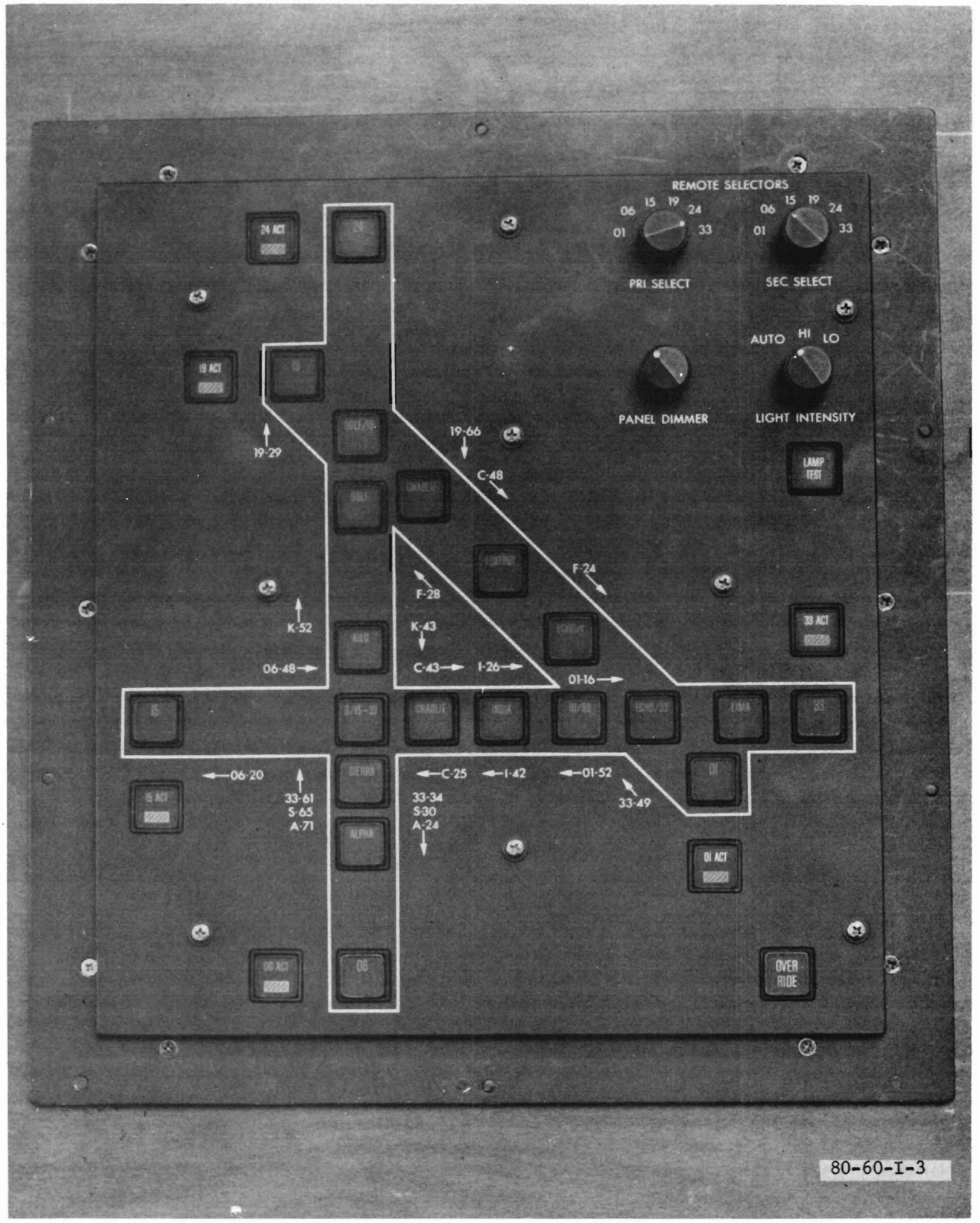


Figure 3-8. Mimic Type VICON Control Panel With Switch Identification

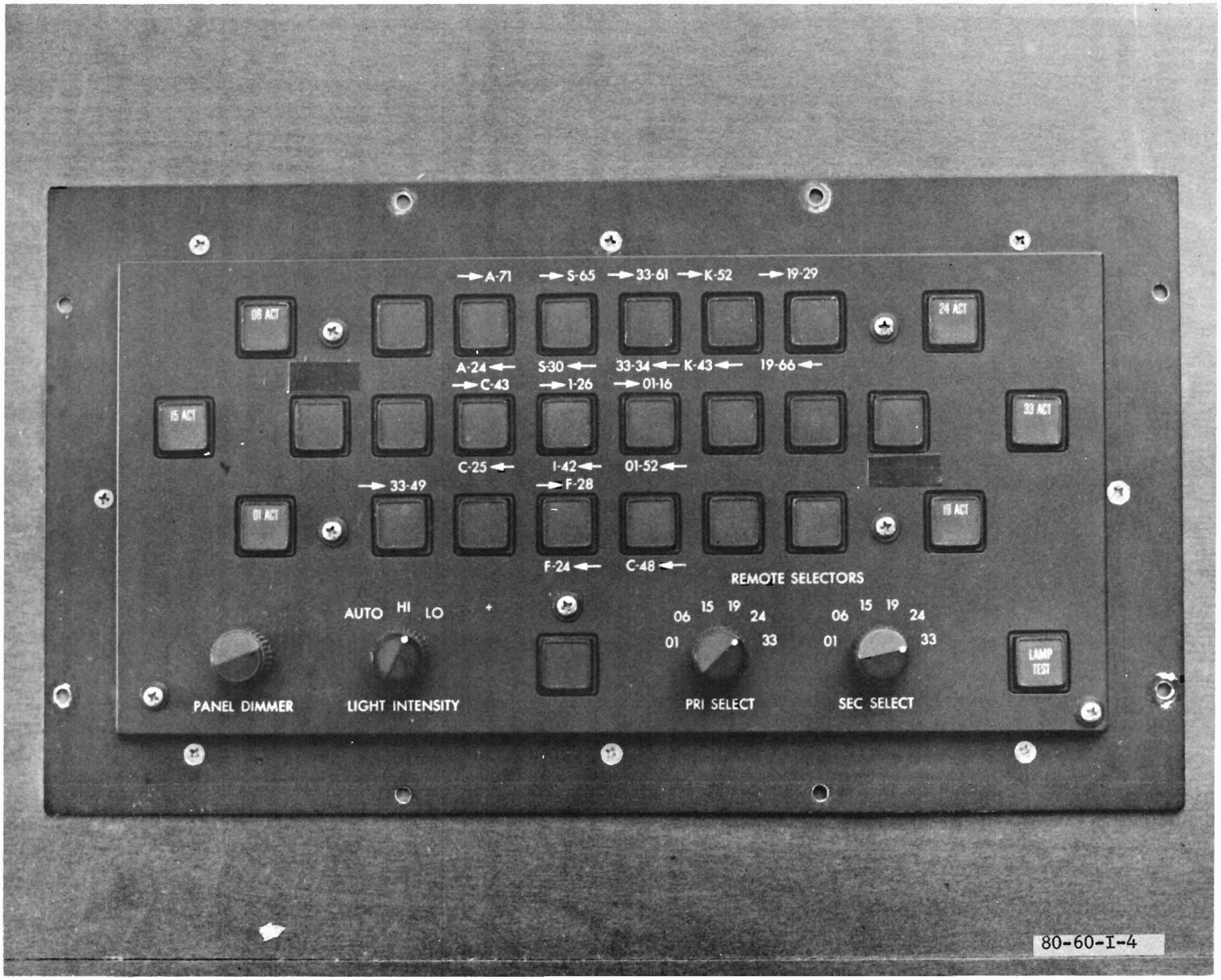


Figure 3-9. Matrix Type VICON Control Panel With Switch Identification

IV. ANALYSIS

A. Fault Tree Methodology

1. General Description

a. Introduction. Fault Tree Analysis (FTA) is a particular application of formalized deductive logic for safety systems which depicts the inter-relationship of component states or their combinations that can result in the occurrence of a specified undesired system state defined as the top event of the Fault Tree. The Fault Tree considers only those component states that might contribute to the system failure, as opposed to a system reliability (availability) model which considers every component state in the system. Consequently, for a complex system, the Fault Tree often provides a simpler and more efficient means of determining system reliability or availability than the use of the totally descriptive system model.

b. Fault Tree Construction. Construction of a Fault Tree begins with the definition of the top (undesired) event of the tree. The events which constitute direct causes of the top undesired event are shown in a manner displaying their logical relation to this undesired event. The causes of the second tier events are in turn shown logically related to each of the second tier events. This process is continued until a set of sequences of events are developed linking the top event to each of the basic causes of interest or basic events that appear at the bottom of the Fault Tree, typically the failure of a component such as a capacitor, relay or transistor.

Since the elements of a Fault Tree are the same for all types of events and systems being analyzed, a standard set of symbols may be used to represent such events and operations. The symbols used in this report are those most commonly in use today and include the rectangle, the diamond, the circle, and the triangle, together with the logic symbols for AND and OR gates.

The rectangle defines an event that is the output of a logic gate and is dependent on both the inputs to the gate and the type of the gate.

The circle represents an event considered basic to a given Fault Tree and is used here to represent inherent failures of system elements. The diamond is used to represent an event, other than the failure of an elementary component, which is purposely not developed further; and will always indicate the limit of resolution of a given Fault Tree. Hence, either a circle or a diamond will be the final symbol in any branch of a Fault Tree.

The triangle, with an identifying letter or number, is used as a transfer symbol to avoid repeating sections of the tree. The Transfer-Out symbol represents all of the sequences appearing between the symbol and the bottom of the tree on the page where the symbol appears and indicates that these sequences form a part of another tree appearing on a different page. The Transfer-In symbol indicates that a branch appearing on another page is connected at the point of the symbol. The Transfer-In symbol includes the page location of the referenced branch.

Logic symbols (AND and OR) are used to depict the dependence of an event on the occurrence of one or more other events. The AND gate symbol is used to portray the situation in which the output event will occur only when all of the input events co-exist while the OR gate symbol represents the case in which the output event will occur if any one or more of the input events occur.

c. Quantitative Fault Tree Evaluation. Evaluation, as used here, refers only to the calculation of the probability of occurrance of the top event of the tree although Fault Trees may also be evaluated qualitatively to determine sets of basic events that will cause the top event to occur.

Fault Tree evaluation is performed in three steps: (1) reduction of the tree to a form free of dependencies, (2) assignment of probabilities of occurrance to each of the basic events at the bottom of the tree, and (3) combination of the probabilities upward according to the logic of the tree to produce the probability of the top event.

The reduction of dependencies essentially consists of the repeated application of the following rules of Boolean Algebra:

$A + A = A$ (input event A OR input event A is equivalent to output event A)

$A \cdot A = A$ (input event A AND input event A is equivalent to output event A)

$A + 1 = 1$ (input event A OR input One is equivalent to output One)

$A + A \cdot B = A(1 + B)$

$= A$ (input event A OR input event A AND input event B is equivalent to output event A).

These rules are used to eliminate repeated events that occur in various branches of the Fault Tree so that when numerical probabilities are assigned, the probability of any single, independent, event is used only once in the system/equipment analysis. Reduction of the Fault Tree can also be accomplished by the method of minimal cut sets, a technique typically used in qualitative tree analysis.

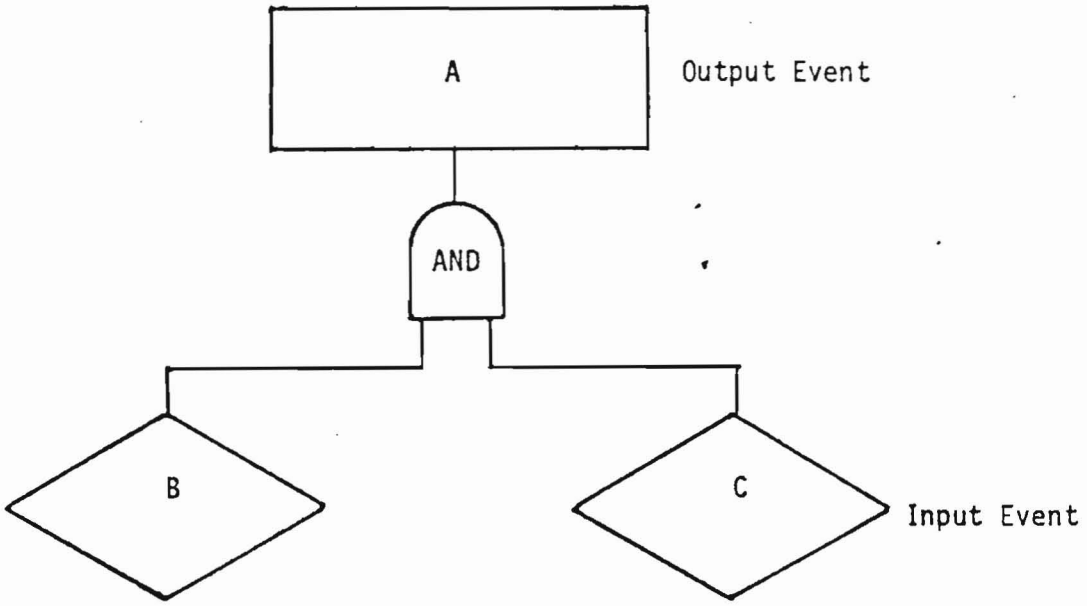
Probabilities are combined across gates according to two simple rules:

- The probability of the output event of an AND gate is the product of the probabilities of the input events.
- The probability of the output event of an OR gate is the sum of the probabilities of the input events.

It should be noted that while the computational method for AND gates is exact, the method given for OR gates is an approximation whose accuracy depends on both the value of the input probabilities and the number of inputs to the gate. Accuracy decreases with increasing input probabilities and with increasing number of inputs; however, the input failure probabilities typically encountered in any reasonably reliable equipments are sufficiently small so that nearly unrestricted use may be made of this approximation without unreasonable error.

These computational rules are derived from basic theorems of probability covering the probability of independent events and the probability of the union of events. These theorems apply to any number of events but are best illustrated by considering the case of two events or two inputs to a given gate.

An AND gate symbolizes the situation in which all input events must co-exist for the output event to occur so that in the tree



event A will occur if and only if events B and C occur simultaneously. Probability theory states that the probability of two independent events both occurring is the product of their individual probabilities so that if B and C are independent and

$$P(B) = .05$$

and

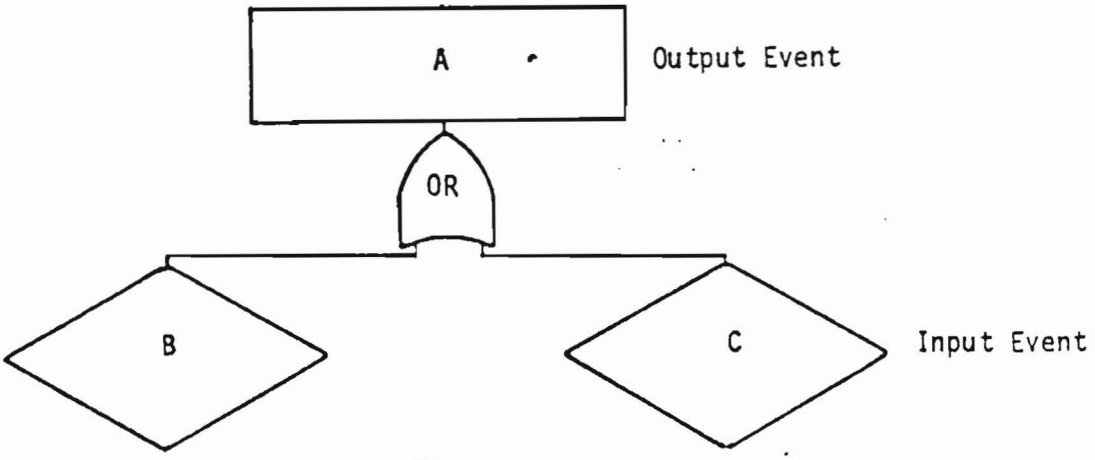
$$P(C) = .03$$

then

$$P(A) = P(B) \cdot P(C)$$

$$= .0015$$

An OR gate symbolizes the situation in which one or more input events must exist for the output event to occur so that in this tree



event A will occur if event B occurs or event C occurs or both events B and C occur; i.e., event A is the union of events B and C. Another well known theorem of probability states that the probability of the union of two events is the sum of the probabilities of each of the individual events minus the probability that both events occur. If the two events are independent then the probability that both occur is the product of their individual probabilities of occurrence, or

$$\begin{aligned} P(A) &= P(B) + P(C) - P(B)P(C) \\ &= .05 + .03 - (.05)(.03) \\ &= .0785 \end{aligned}$$

It can be shown that this formula extends to any number of input events so that for three independent input events

$$\begin{aligned} P(A) = P(B) + P(C) + P(D) - P(B)P(C) - P(B)P(D) - P(C)P(D) \\ + P(B)P(C)P(D) \end{aligned}$$

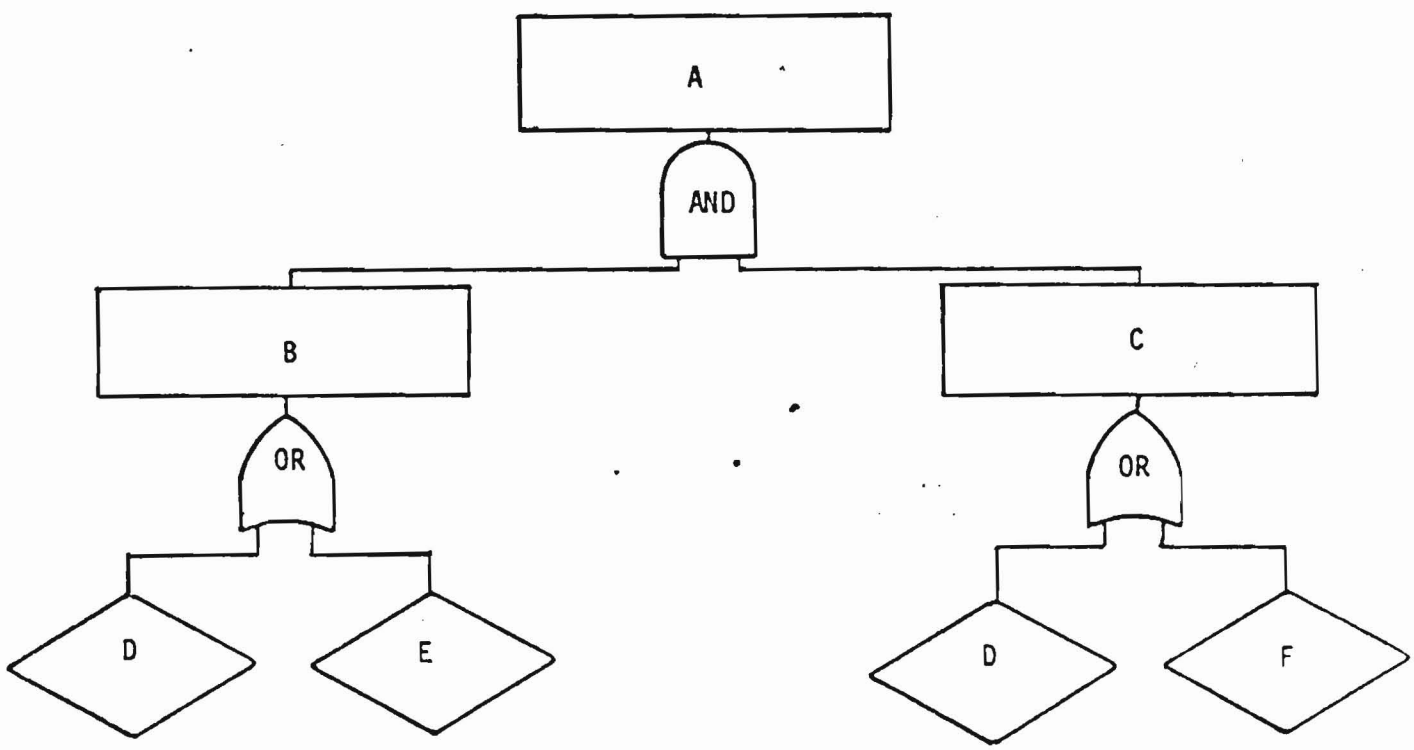
and for four events

$$\begin{aligned} P(A) = {} & P(B)+P(C)+P(D)+P(E) - P(B)P(C) - P(B)P(D) \\ & - P(B)P(E) - P(C)P(D) - P(C)P(E) - P(D)P(E) \\ & + P(B)P(C)P(D) + P(B)P(C)P(E) + P(B)P(D)P(E) \\ & + P(C)P(D)P(E) - P(B)P(C)P(D)P(E) \end{aligned}$$

Clearly, use of the exact formula with a large number of input events results in a lengthy and tedious calculation that is quite subject to error. It is far more convenient to use the approximation stated previously, i.e., the probability of the output event of an OR gate is the sum of the probabilities of the input events. The error in this approximation depends on both the number of inputs and the value of the input probabilities. For example, with the two input case, illustrated

there is a 5% error in P(A) when P(B) = P(C) = .1 and 1/2% error if P(B) = P(C) = .01. If, however, the input probabilities are all equal at .01, the error is 1/2% for two inputs, 1% for three inputs, and 1.5% for four inputs. While no absolute statements can be made concerning the accuracy of this approximation, past experience has shown errors of 1% or less can be expected in the Fault Trees of typical complex systems of eletronic components. Maintenance of a reasonable error level in using this approximation is aided by the fact that in the typical Fault Tree the larger numbers of inputs to an OR gate occur near the bottom of the tree which in turn implies lower values of input probabilities.

It must be noted that the computational forms given here for combining probabilities across both AND and OR gates require all input events to be mutually independent. The structure of the Fault Tree will often conceal dependencies, particularly if the tree is analyzed a branch at a time, making it imperative that a Boolean reduction be routinely made the first step of every Fault Tree analysis. For example, in the tree



consideration of each gate separately does not reveal any dependencies; i.e., the inputs to the AND gate are B and C, the inputs to one OR gate are D and E, and the inputs to the other OR gate are D and F; however, looking at the tree as a whole, the inputs to the AND gate are not independent since both ultimately contain the event D. Application of the algorithms for combining probabilities across gates yields:

$$P(A) = P(B) \cdot P(C)$$

$$P(B) = P(D) + P(E)$$

$$P(C) = P(D) + P(F)$$

hence

$$P(A) = [P(D) + P(E)] \quad [P(D) + P(F)]$$

which if

$$P(D) = .02$$

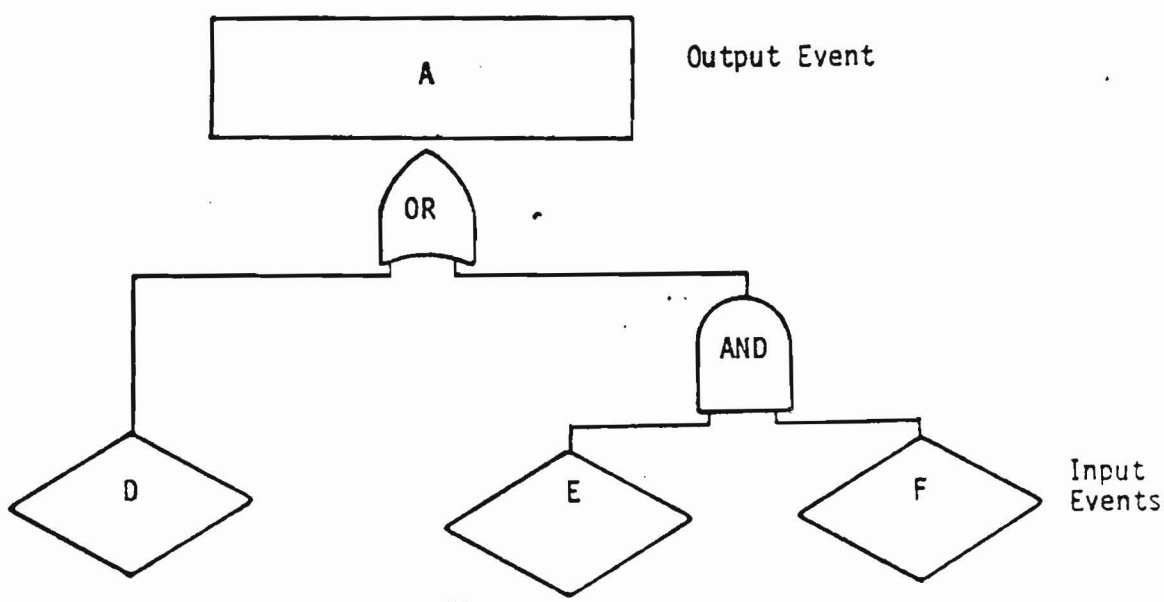
$$P(E) = .03$$

$$P(F) = .01$$

results in

$$P(A) = .0015$$

If, however, a Boolean reduction of the tree is performed, the resultant tree has the form



which contains no dependencies. Hence the correct value of the probability of event A is

$$P(A) = P(D) + P(E)\,P(F)$$

$$= .0203$$

The 93% error obtained in this example by combining probabilities involving dependent events makes clear the importance of reducing the tree before performing these calculations.

2. Application to VICON

a. Tree Construction. The application of Fault Tree Analysis to the determination of the reliability of the VICON System begins with the construction of a Fault Tree that is based on the definitions of system failure and runway failure given in Section II. A.

Construction is begun by stating the basic undesired event at the top of the tree, i.e., the VICON system is unavailable for use. From the definition of system failure and the runway configuration at Bradley (see Figure 3-6) it can be seen that the VICON system is failed if any of the following twelve pairs of runways are simultaneously failed: (1, 6), (1 & 15), (1 & 24), (1 & 33), (6, 15), (6, 19), (6,33), (15,19), (15,24), (19, 24), (19,33) and (24, 33). This is reflected in the Fault Tree (see Appendix B, Figure 1) by having a twelve input OR gate to represent system failure, each input in turn being an AND gate whose two inputs correspond to one of the noted runway pairs. The gates involved are the OR gate TOP and the AND gates G-3 through G-14. Gates G-1 andG-2 are dummy gates necessary to the proper operation of the computer program used in plotting the fault trees, they are not related to any element of the VICON system and have no effect on the analysis. The other inputs to gate TOP (C1 and C2) occupy their positions in the tree as a result of preliminary analysis rather than as a result of basic tree construction principles; hence, they will be discussed in subsequent paragraphs of this section.

Development of the next level of the Fault Tree follows directly from the departure point utilization statistics for Bradley. For example, in the case of runway 06, the runway is failed when any two of the four lamp

clusters (2, 4, 5, and 19) are out of service, since these failures constitute a 50% loss in total lamp clusters. This is shown in the Fault Tree by OR gate 26 and AND gates 27 through 32. Runway 06 is also failed whenever cluster 19 alone is failed since this cluster will handle 93% of the departures from runway 06. This situation is represented in the tree by showing gate 26 and loss of cluster 19 in an OR combination (gate 25). The lamp cluster failure combinations needed to produce a runway failure are determined in a similar fashion for each of the other five runways.

Development of the tree is completed by analyzing the system and diagramming all the possible causes for the failure of each of the 21 lamp clusters. Taking cluster 10 as an example, this cluster will fail whenever any of the three major elements shown in Figure 3-1 fail; i.e., the lamp cluster itself, the control and monitoring equipment and the interconnecting circuitry. This is represented on the lamp cluster fault tree (Figure 11 in Appendix B) by showing the lamp cluster (G-56), the tower-monitor circuit (G-250) and the control circuit (G-195) connected by an OR gate (C-55) at the top of the lamp cluster tree. G-145, G-184 and G-202 are also connected to the top of the tree even though these items are shown in Figures 3-1 through 3-5 as a part of the lamp control circuit. These items are shown separately since they are common to all lamp clusters; i.e., there is only one intensity selector, one pulser and one 48 VDC supply for the entire VICON system; the remaining items in Figure 11 are related only to lamp cluster 10. This separation of common and unique items in the lamp cluster 10 tree is made in the interest of computer utilization efficiency. The separation permits calculation involving the common items to made once and included in all lamp cluster trees by reference rather than repeating these computations twenty-one lines.

Continuing through the tree, component relationships shown by Figures 3-2, 3-3, 3-4 and 3-5 are translated into the failure logic of the tree. In the simplest case, the lamp cluster (G-56) fails whenever any one of the three series filament lamps fails. Even in the legs of the tree containing larger numbers of components, the failure relationship is essentially that of a lamp cluster failing whenever any associated component fails. The only major exceptions is in the lamp intensity circuit where AND gates G-147, G-148 and G-149 are used to reflect the fact that intensity is lost only if both manual and auto intensity control are failed simultaneously.

This fault tree development procedure is followed for every branch of the tree until each branch ends at the component level at which repair is normally made, as dictated by the maintenance policy established for the Bradley installation. This results in a wide variation in the complexity of the components found at the ends of the various branches. For example, the branch from G-707 terminates in simple items (fuses) which cannot be further subdivided and in complex items (power supply) which could be broken down further if the repair philosophy of VICON required power supply repair instead of replacement.

When all branches of the tree had been carried to the level at which repair is accomplished, the fault tree design was complete.

b. Analysis

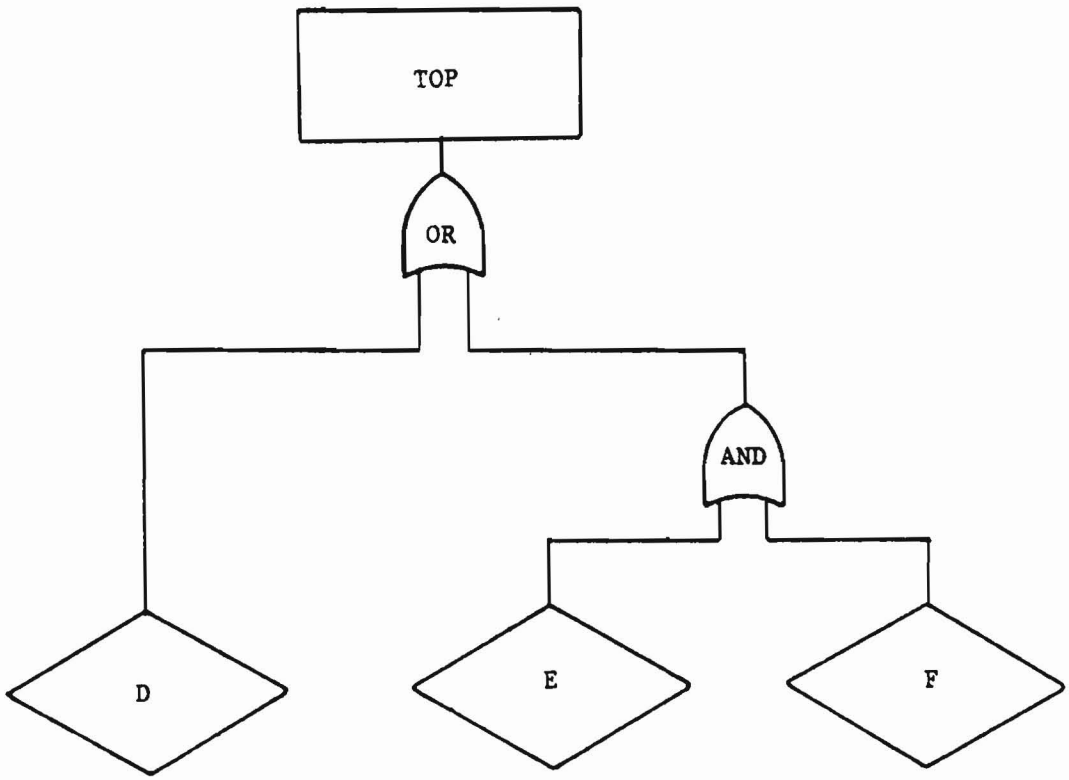
The analysis of the VICON fault tree was conducted in three steps: (1) a preliminary manual analysis, (2) a computerized qualitative analysis and (3) a computerized quantitative analysis. The preliminary analysis was performed solely for the purpose of expiditing the computerized analyses and the computerized plotting of the trees. The qualitative analysis was conducted to assess the relative impacts of the failures of various components on total system performance. The results of this analysis were used to locate weaknesses in the design configuration, determine the need for reduncancy and identify critical components for use in the spare parts stock level analysis. The quantitative analysis consisted of a numerical assessment of the reliability (or availability) of the VICON system.

(1) Preliminary Analysis -- The preliminary analysis consists of a manual inspection of the initial fault tree construction to identify those components, if any, that are common to all branches of the tree. These common components are deleted from all branches and replaced by a single entry to the top gate of the tree. (The two power supplies shown at the top of Figure 1 of Appendix B are such components in the VICON system). This rearrangement drastically reduces the number of steps in the computerized analysis. Note that the preliminary analysis need not be exhaustive, the computerized analysis will function without any preliminary analysis.

(2) Qualitative Analysis -- The qualitative analysis consisted of the reduction of the fault tree to its minimal cut sets.

A cut set of a fault tree is defined as any set of elementary events whose occurance cause the top event to occur. In terms of the VICON system a cut set is any component or collection of components whose failure causes

the system to fail. A cut set is minimal, if it cannot be reduced and still insure the occurance of the top event. As an illustration of cut sets and minimal cut sets consider the following fault tree.



The cut sets of this tree are (D), (D, E), (D, F), (D, E, F), (E, F). The minimal cut sets are: (d),(E,F). Cut sets (D,E), (D, F), (D, E, F), are not minimal since they can be reduced; i.e., element E, removed from (D, E), element F from (D, F) and E and F from (D, E, F) and the top event will still occur.

The toal number of cut sets for a fault tree the size of the VICON tree may well number in the hundreds of thousands making it impossible to determine them by manual inspection and impractical to find all of the cut sets even with a large digital computer. It is not, however, necessary to find all of the cut sets of a fault tree to determine the system reliability or to analyze the system for design changes to improve reliability. The number of cut sets required for the calculation of system reliability depends on both system configuration and component type and application; this will be discussed in the section on quantitative analysis. For qualitative analysis, cut sets are enumerated according to size beginning with sets of size one, and continuing until the analyst has sufficient information to determine the impact on system reliability. The number of classes of cut sets that must be obtained varies with the parameters of the system and must be established by the analyst for each system.

Determination of all cut sets of size one and size two is sufficient for the qualitative analysis of the VICON system. Reference to Table 1 in Appendix A shows that the VICON Fault Tree reduces to 11 cut sets of size one and 6432 cut sets of size two. The existence of cut sets of size one means that there are components in the VICON system whose failure, with all other components operating, will cause the entire VICON system to be inoperative. The number of these components, eleven, is small enough to permit consideration to be given to redesign in each of these eleven areas. The 6432 cuts sets of size two represent situations in which two components must fail simultaneously for system failure to occur, and should therefore be considered satisfactory. Furthermore, consideration of 6432 areas for design change is not a modification but a complete redesign. Hence, the qualitative analysis for VICON is limited to cut sets of size one.

Each of the cut sets of size one was reviewed to determine the hardware relationships that cause system failure to result from a failure of single component and to assess the feasibility of a design change to eliminate the dependence of the system on a single component.

Components A1-48V, T1-48V, 48V X 1, 48V X 2, 48VF1 and 48VF2 are all part of the 48VDC supply used for the relays of the hardwire control system; they are respectively the power supply, an external input transformer for the power supply, the input circuit breakers for the power supply and the output fuses for the power supply. Failure of any one of these components will cause loss of the hardwire control relays in all twenty-one lamp circuits. Lamp clusters I8, 19, 20, and 21 will operate, via radio-link only, with the 48VDC supply failed; however, under the definitions of runway and system failure being used, the system would be considered failed. The simplest and most cost effective method of improving system reliability in this area is to add another complete set of those six components to create two parallel 48VDC supply systems.

Items C1 and C2 are also power supplies, C1 being the lamp/indicator supply for the tower monitor circuits while C2 is the 24VDC supply for the relays in the tower monitor circuit. Loss of C1 will cause the loss of all indicator lamps making it impossible for the controller to verify system operation and resulting in a system failure. Loss of C2 will make the control and timer relays inoperative in the tower control circuitry for all twenty-one lamp clusters, also a system failure. As in the case of the 48VDC supply, it is recommended that dual redundant systems be used for both lamp/indicator and relay supplys.

M1 is the pulser which is used to apply pulsating ground to the lamp clusters in order that the lamps flash when operating; however, since all lamp grounds in the hardwire control system are controlled by the same

pulser, loss of M1 makes all twenty-one hardwire control circuits inoperative. The four lamps with radio-link will remain functional on radio-link only, but the system is by definition failed.

In order to eliminate the total system dependence on a single pulser, it is recommended that the system be modified to use a separate pulser in the ground circuit of each lamp cluster, or if it is desired to keep the hardwire and radio-link controls as independent as possible, two pulsers will be necessary for each lamp having dual control. If individual pulsers are used for each lamp cluster, the three pulser relays now used to divide the current load are no longer necessary and should be eliminated.

The intensity selector switch, S29, controls the intensity of every lamp cluster on the field, hence failure of this switch will effect the operation of all clusters; the effect depending on the failure mode of the switch. The switch can fail in five modes; (1) maintain lamps at high intensity regardless of desired operation (2) maintain lamps at low intensity, (3) preclude lamps being operated at low intensity, (4) preclude automatic intensity selection and (5) preclude manual intensity selection. Hence, while switch failure will effect all lamp clusters, failure will occur only if ambient light conditions exist which require a particular lamp intensity for VICON operations, a situation which has not yet been evaluated. It is therefore recommended that no change be made in this area.

The override switch, S27, is used by the controller to cancel any or all of the VICON lamp clusters that are operating. The effects of the failure of this switch on system operation depend on the mode of the failure. If the switch fails so as to lose electrical continuity or mechanically so that once operated it will not return to the normal position, the holding

circuit ground will be lost (hardwire and radio-link) to all lamp clusters and the system will be totally inoperative. If, however, the switch fails mechanically so that it cannot be operated, the controller loses the override control function and any VICON lamp cluster that has been turned on will remain illuminated until shut off by either the timer or the microwave detector. The later failure mode could lead to an aircraft receiving an unintended VICON clearance; however, for this to occur the controller must make an error in granting a clearance at the same time that this failure mode exists. For this situation to result in an unintended take off, the pilot in command of the aircraft must also commit an error and take off without voice clearance.

Circuit modification can be made in this area to reduce the probability of one failure mode or the other, but not both. If it is desired to reduce the probability that an open switch will make all lamp clusters inoperative the single override switch should be replaced by individual override switches for each runway. This modification would have two draw backs: (1) it will add slightly to operator inconvenience and (2) it will increase the probability of the granting of an unintended VICON clearance due to switch failure. On the other hand, if it is desired to reduce the probability of an unintended VICON clearance, the single override switch should be replaced by two such switches in series providing for both an override and an emergency override function.

It is impossible to make a complete assessment of this situation on the basis of qualitative analysis alone and data are not available on the probabilities of human error making a quantitative analysis of the situation impossible. It is suggested, however, that since two simultaneous failures (one component, one human error) are needed to cause an unintended

clearance and an additional human error needed for unintended take off, the failure closed mode of the switch can be ignored. Hence, it is recommended that the decision to use one or six override switches be based on the operator convenience factor; the single switch being retained the use of six switches presents an unacceptable degradation in convenient operation.

There is one additional design change to be considered that results from engineering analysis rather than analysis of the fault tree. The flashing of the monitor lights that indicate lamp cluster operation to the controller are controlled by a different shut-off timer than the one that controls the flashing of the VICON lamps themselves. It is recommended that the same device be used to control both the lamp cluster and the tower indicator to preclude the possibility of an erroneous indication resulting either from component failure or human error in setting the times.

(3) Quantitative Analysis - The quantitative analysis of the VICON fault tree serves to: (1) obtain a numerical measure of overall system ability to perform its intended function, and (2) provide a numerical assessment of the impact on system performance of each of the design changes recommended in the qualitative analysis section.

As the first step in computing a numerical index of VICON system performance it is necessary to define an appropriate system level measure that is related to determinable component characteristics. It can be noted from the definition of runway failure that the key to VICON performance is the state (functioning or non-functioning) of one or more lamp clusters at the time these clusters are called upon for use. It is immaterial in terms of this definition when a lamp cluster entered the state (functioning or non-functioning) in which it is found when it is asked to operate. In other words, a non-functioning lamp cluster counts equally in assessing runway (and system) failure whether the cluster failed days, hours, or moments before an attempt to use the lamps. Conversely, the cluster counts equally as a success whether it has never failed since installation or whether it was repaired only moments before an attempt to use it to grant a VICON clearance. This characteristic is known technically as Availability and is formally defined as; The probability that a device is in an operable and committable state at any instant in time when it is desired to use the device. Availability can be assessed at any device level; system, equipment or individual component and is related to the device characteristics of reliability and maintainability through the expression

$$A = \frac{MTBF}{MTBF + MTTR} \qquad (1)$$

where

A = Availability

MTBF = mean time between failures, a measure of device reliability

MTTR = mean time to repair, a measure of device maintainability

From this equation it can be seen that availability measures the proportion of total time during which the VICON system is capable of operation, taking into account both the frequency of failure (MTBF) and the speed with which a failed item can be restored (MTTR). The importance of using Availability as the measure of performance for any repairable item rather than Reliability, defined as the probability of no failure in a given time, can be seen by comparing the Availability and Reliability values for a single component of the VICON system, one of the lamps. The manufacture of these lamps quotes their MTBF to be 1000 hours and the MTTR has been estimated to be 1 hour. Lamp reliability is determined from

$$R = e^{-\left(\frac{1}{\Theta}\right) t}$$

where

R = Reliability

Θ = MTBF

e = 2.7183

t = time in hours

(This equation assumes exponentially distributed failure times, the customary assumption in the case of electronic/electrical devices). Using time periods of one day, one month and six months:

R_1 day = 0.9763

R_1 month = 0.4868

R_6 month = 0.0133

Lamp availability is, however:

$$A = \frac{1000}{1000 + 1} = 0.9990$$

regardless of the length of time the lamp has been operational.

VICON System Availability is determined by using the logic of the fault tree to combine the unavailabilities of the individual components into a system unavailability figure whose complement is the desired numerical value.

Unavailabilities are determined for each component of the VICON System as the complements of values calculated by equation (1) using MTBF and MTTR values obtained from various sources. Component MTBF values were obtained from the supplies of the components when possible or from published tables of generic failure rate (the reciprocal of MTBF) such as MIL-HDBK-217. Vendor data are considered to be superior when available as they are more likely to reflect current state of the art than information published in handbooks having lengthy revision cycles. The failure rates in MIL-HDBK-217 do offer the advantage of being quite conservative so that their use involves no danger of over estimating the VICON System's capabilities. Component MTTR values were determined from estimates made by personnel experienced in maintaining the VICON System at Bradley and the predecessor system at NAFEC.
This method is considered superior to the handbooks values since MTTR is so highly dependent on system configurations that handbook values are crude approximation at best. Table 4-1 lists the major components of the VICON System with their failure rates and MTTR values together with the source of

TABLE 4-1

SOURCES OF FAILURE RATES

COMPONENT	No. Used	Repair Rate (Repair/Hour)	Failure Rate (Failures/10^6Hr)	Source of Failure Rates
Twr-Microwave Switch	4	0.67	0.011	Mil-HDBK-217C
300-33086 Microwave Detector	4	0.40	50.290	Omni-Spectro (Manufacturer)
91760-002 Master Transceiver	1	1.00	46.474	Computed Based on MIL-HDBK-2176
91760-002 Remote Transceiver	4	0.67	46.474	"
20-20 Runway Act. Switch	6	0.33	66.670	Manufacturer's Spec.
20-20 Override Switch	1	0.33	66.670	"
20-20 Departure Act. Switch	20	0.33	66.670	"
156-146100 Twr Control Relay	20	0.33	0.300	MIL-HDBK-217C
a43-01a Twr Timer Relay	20	0.33	0.790	"
1N 3613 Diode	59	0.33	0.036	"
Rem-pri Sel Switch	2	0.33	0.670	"
Rem-pri Act Switch	2	0.33	0.011	"
6263b 0-20 Volt Pwr Supp.	1	1.00	21.097	Hewlett-Packard (Manufacturer)
62024e 24 volt Pwr Supp.	1	1.00	7.358	"
AU-5894 48 Volt Pwr Supp.	1	1.00	43.45	NAVSHIPS 9382

TABLE 4-1

SOURCES OF FAILURE RATES

COMPONENT	No. Used	Repair Rate (Repair/Hr)	Failure Rate (Failures/10^6Hr)	Source of Failure Rates
Q6-6-PAR-562 Runway Lamp	63	1.00	1,000	GE (manufacturer)
REM-HDWE SEL. SWITCH	4	0.67	9.011	MIL-HDBK-217C
Intensity SEl, SWITCH	1	0.30	0.670	"
MR 5498-48VDC Auto Cmtl Relay	1	0.67	0.300	MIL-HDBK-217C
MV 5498-48VDC Lon Cntl Relay	1	0.67	0.300	"
KR 5498-48VDC Relay	23	0.67	0.300	"
Pbtb-365 .5 mfd Capacitor	25	0.67	0.031	"
At-15 Master (ASR) Photocel	1	0.67	0.031	Vitro Labs Reliability & Availability Analysis for solid state system sequence, September 1977
At-15 Remote Photocel	4	0.50	0.031	
100 w., 2 watt resistor	25	0.67	0.016	MIL-HDBK-217C
Kaa 20 Lamp P-S Fuse	7	1.33	0.100	"
Kaa 20 remote lamp fuse	4	1.33	0.100	"
W10G2 Lamp P-S Variac	7	0.67	0.106	"

TABLE 4-1

SOURCES OF FAILURE RATES

COMPONENT	No. Used	Repair Rate (Repair/Hour)	Failure Rate (Failure/10^6 Hr)	Source of Failure Rates
PRD11ayo hi-lo sel relay	7	0.67	1.000	MIL-HDBK-217C
PRD11ayo power relay	21	0.67	1.000	"
PRD11ayo remote power relay	4	0.50	1.000	"
PRD11ayo remote hi-lo relay	4	0.50	1.000	"
PRD11ayo pulsar power relay	4	0.67	1.000	"
10601eelb Master (ASR Pulsar	1	0.67	0.300	"
10601eelb Remote Pulsar	4	0.50	0.300	"
Mov-130V Surpress	46	0.67	0.720	"
Cub51-70120 timer relay	21	0.50	0.790	"
Cub51-70120 remote timer relay	4	0.50	0.790	"
112 XAX 1195 Monitor Relay	21	0.67	0.300	"
Fusetron 2a for 48 Volt Fuse	2	0.67	0.100	"
48 Colt P-S Transformer	1	0.67	0.053	"
Kup11a15-120V Remote Aux. Relay	4	0.50	0.300	"
112 xax 595 Rem. monitor relay	4	0.50	0.300	"
W8g2 Remote Variac	4	0.67	0.106	"
Remote Power Switch	4	0.67	0.011	"
48 PS Volt Circuit breaker	2	0.67	2.000	"

the failure rates. It should be noted that wire and cable are not included in this list. It is recognized that these items do fail; however, true random failures of these items are so rare as to be marked by failures originating from lot peculiar quality problems, human errors by installation and maintenance personnel and acts of nature. Any estimate of failure rates for wire and cable will therefore be representative of a particular production lot and a particular installation not of wire and cable behavior in general. The impact of neglecting wire and cable in the calculation of VICON System availability will be negligible provided wire and cable were thoroughly inspected prior to installation and properly tested following installation.

Once component unavailabilities have been determined, system unavailability is obtained by using the combinatorial rules given in Section A.1 of this chapter (multiplication of AND gate inputs and addition of OR gate inputs) in the reduced tree described by the minimal cut sets. From the definition of minimal cut sets, it can be seen that a fault tree constructed of all the minimal cut sets is equivalent in logic to the original tree and is also free of dependencies thereby allowing use of the computational rules of Section A-1 of this Chapter. The equivalent cut set tree is constructed by taking the OR combination of all cut sets, where cut sets of more than one component are represented by the AND combination of all components in the set. Consequently, the system unavailability value is obtained by summing the unavailabilities across all cut sets, the cut set unavailabilities having first been found as the product of the unavailabilities of their components. The figures across any line of appendix A represent; in the first column, the cumulative unavailability due to all cut sets appearing from the top of the table through the indicated line; in the second column, the unavailability of the cut set on the indicated line; and in the remaining columns, the unavail-

abilities of each component in the cut set on that line. The final number in the first column of figures (0.0005364569) is the system value and corresponds to a system availability of 99.94%.

It should be remembered that the numerical value of VICON System availability reported here is based on the particular installation at Bradley International Airport and on the definition of system failure given in Chapter 3, which is in turn based on a primary mission of data collection rather than aircraft control. Since the system failure definition used is also reasonable when referred to the aircraft control mission, the 99.94% availability figure obtained may also be considered valid for an operational system installed at Bradley. Availability as a measure of VICON System performance does not, however, give any consideration to the situation of inadvertent granting of a VICON clearance. Final analysis of any operational VICON System should include an assessment of the inadvertent clearance situation.

It can be seen from Appendix A that the 11 cut sets of size one contribute approximately 25% of the total system unavailability with the remaining 75% of the unavailability being associated with the 6432 cut sets of size two. It is therefore reasonable to concentrate on those hardware items associated with the size one cut sets in any effort to improve system availability through design change. The results of the qualitative analysis reported in the preceding section have in fact recommended design changes associated with 10 of the 11 size one cut sets. To assess the impact of these recommendations, the changes are considered in three groups: (1) use of dual redundant power supplies instead of single units now used, (2) redundant power supplies plus change to individual pulsers for each lamp cluster and (3) both changes (1) and (2) together with use of individual override switches for each runway. To determine the numerical impact of change (1) it is only necessary to note that this change will reduce the unavailability contribution

of each power supply component to one-half its present value; subtracting one-half of the unavailability contribution of the eight power supply items raises system availability forms its present value of 99.94% to 99.95%. The added effect of the recommended pulser change can be approximated by noting that with the change the pulser will no longer appear as a cut set of size one but as cut sets of size two corresponding to all possible combinations of pulser failures with each of 12 other components over each of 12 possible runways pairs or 144 cut sets of size two. This will result in an increase in system availability to at least 99.97%, (approximated using combination of pulser and highest failure rate component). Finally the override switch modification will have the same general effect as the pulser modification and will increase system availability to at least 99.99%. Care must be taken in interpreting these figures since what appears to be only a modest improvement in system availability (99.94% to 99.99%) is actually the result of an 83% reduction in the current system unavailability, a sufficiently significant achievement to verify the importance of the recommended design changes.

The reliability of the VICON System is not a basic factor in assessing the performance of the Bradley installation in collecting assessment data; however, the reliability associated with the granting of an individual VICON clearance is of interest with regard to assessing the validity of the data collected at Bradley and in forecasting the ability of an operational VICON System to provide clear, unambiguous information to departing aircraft.

Using the failure rates given in Table 4-1, the total failure rate for those items necessary to the operation of any single lamp cluster is 3477.17 X 10^{-6} failures per hour. Assuming that the average VICON clearance operation requires 20 seconds, the probability of no failure occuring while the clearance is in process is 99.998%. Hence, it can be expected that one failure will

occur in every 50,000 clearances.

The Bradley installation contains two cases of competing design concepts in simultaneous operation for test purposes; timer vs. microwave detector for system shutoff and hardwire vs. radio link for the interconnecting circuit between operator controls and lamp clusters.

Reliability comparisons for each pair of competing concepts provide one basis for selecting the concepts to be preferred in an operational VICON system.

Comparison of the timer vs. microwave detector is made simply on a component basis while comparison of the hardwire vs. radio link systems is made on the basis of the aggregate of all components needed for the operation of any one single lamp cluster.

The reliability of the timer over a period of 20 seconds is 99.9999996% while that of the microwave detector is 99.9999721%. Hence, in terms of clearance operations, the timer can be expected to cause 1 failure every 250,000,000 operations while the microwave detector will cause 1 failure in approximately 300,000 operations. A similar comparison of the two control systems shows the hardwire system to have a 20 second reliability of 99.9981477% while the radio link value is 99.9980959%. This corresponds to approximately 1 failure in 54,000 operations for the hardwire system and 1 failure in 53,000 operations for the radio link.

Availability comparisons shows a similar result with timer = 99.999 vs. microwave detector = 99.990% and hardwire = 99.62% vs. radio link = 99.61%.

It is clear that the timer offers a clear cut advantage over the microwave detector in terms of reliability and availability while the hardwire and radio control links have approximately the same impact on VICON reliability and availability.

B. Spare Parts Provisioning

This analysis determines the number of spare parts that should be stocked for each component in the VICON system in order to insure that the inherent availability of VICON is not degraded for lack of necessary spares to make needed repairs. It should be noted that the spares provisioning analysis performed is dependent on both the system configuration and the particular components used to implement it. The analysis included here is therefore strictly valid only for the VICON system currently installed at Bradley. However, it provides an illustration of the method for sparing any VICON system and could be used to spare the Bradley system if it were converted to operational status without major changes.

The basis of the analysis performed is the computation of what is termed the PROVISIONING PROTECTION LEVEL for the total VICON system based on a started provisioning period and an assumed set of spares. System provisioning protection level (protection level) is defined as the probability that no system failure remains unrepaired for lack of a spare part or alternatively as the probability that the number of failures in a provisioning period does not exceed the number of spares in stock. (Provisioning period is any selected time span, normally established in response to logistic considerations such as vendor lead time, shipping time, on site spares storage limitations and supply budget cycles). Protection level is computed for different spare part inventories until an inventory is found that provides the desired protection level for the assumed provisioning period.

System protection level is computed from the protection levels of each individual component in the system based on the reliability model of the system. For example in a simple three element series system such as

the system protection level is the product of the protection levels of three components or

$$PLsys = PL_A \times PL_B \times PL_C$$

In a redundant system such as

the system protection level is determined according to the rules for determining system reliablilty so that

$$PLsys = PL_A - (2PL_A - PL_B^2)\ PL_C$$

In this analysis the VICON system has been considered as a fully series system even though this is not true in the functional sense; i. e., there is redundency in the use of radio-links and hardwire control to certain lamp clusters and in the use of both timer and microwave detector shut off in the lamps. The functional redundancy in VICON is, however, provided by different hardware items not by identical sets of redundant hardware as is more common in redundant systems. Hence, VICON must be considered as a series system for sparing in order that spares be made available for all of the component types employed.

Component protection level is computed for each item by computing the probability that the number of failures of a given component during the provisioning period is equal to or less than the number of spares assigned to the given component. This computution is made using the failure rates shown in Table 4.1, the selected provisioning period and the assumption that component

failurers have a Poisson destribution so that

$$PL = \frac{(N\lambda t)^X e^{-N\lambda t}}{X!}$$

where

N = number of parts of a given type in system

λ = part failure rate of a given part type

t = part operating hours in the provisioning period

X = number of spare parts in stock

N and λ are as shown in Table 4.1 and t was determined as follows

It is assumed, for the purpose of the spares analysis as follows, that the VICON system at Bradley would be required to function 18 hours per day every day and it was further assumed that a component was "operating" whenever it was subjected to an applied voltage regardless of whether or not there was current flow. Under these assumptions there are three different values of t that apply to VICON components;

(1) t_1 = 18 hours per day for components such as power supplys, auxillary relays, etc,

(2) t_2 = 1.74 minutes per day for components such as lamps, monitor relays, etc. that function only when a particular lamp cluster is functioning and

(3) t_3 = 36.51 minutes per day for the pulser and pulser relays that operate when any lamp cluster is functioning . Timer t_2 and t_3 were calcuated on the bases of an anticipated 23,000 total operations during the seven month test period and an "on" line for each lamp cluster operation of 20 seconds.

The initial calculation for each component is made with X = o (no spares) and the results combined to determine an initial system protection level. The system protection level is compared to the desired value and if less than the desired value spare parts are added to the inventory according the following rules:

1. Determine component with lowest individual protection level, add one spare for this part and recompute component and system protection levels.

2. Stop if system protection level is equal to or above the desired value, otherwise repeat step (1).

This procedure essentially operates to add spares for the worst component until either the desired system protection level is altered or the component being considered is no longer the worst. In the later case, attention is turned to the new worst component and the process repeated until the desired protection level is achieved.

This procedure will specify the spare parts needed to insure a given system protection level; however, in so doing it may well indicate that no spares are to be stocked for items that have very high reliability. The absence of such spares may be undersiriable in the case of components whose loss will have catastrophic results, regardless of the fact that the component has very high reliability; e. g., the pulser in the VICON system whose loss causes the loss of the entire system. The sparing level computation program provides a means for compensating for this situation by allowing selected components to be declared "critical". When this option is exercised the complete analysis is first made in the normal fashion and all spares assigned to achieve the desired system protection level, then all "critical" components are checked to insure that at least one spare has been provided and additional spared allocated as needed. All of the spares analyses made on VICON generate recommended spares lists both with and without "critical" component consideration.

The spares computation program is implemented to print out intermediate results begining with the achievement of a system protection level of 50% and providing an additional output for each 5% increment in system protection level until the desired result is obtained. This operation is illustrated by Table 4-2A which is the output associated with a VICON spares analysis at a 90% system

protection level over a one (1) month provisioning period.

The initial page of this Table shows the VICON components coded as No. 1, 2, ..., 46 with the zero spares protection level for each component and the number of components installed listed immediately below the code number. The resulting system protection level of 25.29% is also given at the left margin. It should be noted that the there lowest component protection levels are 48% (No. 41), 80% (No. 40) and 89% (No. 38).

The second page of this table shows that a total of 2 spares had to be allocated to raise the system protection level above 50%. Displayed here for each component code number are the component protection level achieved by the first spares assignment and the number of spares of each component provided in this assignment. In accordance with the procedure previously discribed this spares allocation was achieved by allocating spares to the component with the highest failure rate. (No. 41) until its protection level exceeded that of No. 40, then treating No. 40 to bring the system value above 50%.

The remaining pages of Table 4-2A show the successive spares allocations necessary to achieve 5% increments in system protection level up through the desired value of 90%. At this point the sparing allocation without consideration of critical components is complete.

Table 4-2B displays the results of adding the "critical" component spares to the results of 4-3A where the VICON critical components were selected by including all of the components identified by the qualitative analysis as producers of size one cut sets together with all other components having a total population of one in the system. This essentially adds only the two insensity selection relays to the size one cut set items. The protection level value shown in this table are the achieved levels rather than the normal desired values shown in table 4-3A. Nine sparing analyses have been made of the Bradley VICON system representing the combination available from three different system

protection levels, 90%, 95%, and 99% and three different provisioning periods, one month, 3 months, and 6 months. The results of these nine analyses are presented in Table 4.3A without use of the critical component opition and again in Table 4.3B with the addition of critical component consideration.

TABLE 4-2A

PROB. GOAL FOR EQUIP
.9000

PHASE 1

PROBABILITY	PART OR PART TYPE RELIABILITY AND THE ASSOCIATED NUMBER OF PARTS										TOTAL PARTS
	NO= 1	NO= 2	NO= 3	NO= 4	NO= 5	NO= 6	NO= 7	NO= 8	NO= 9	NO= 10	
.25285258	.99962622	.99983263	.99983263	.99998271	.99999440	.99777043	.99997044	.97604644	.98829687	.99590266	470
	1	1	1	1	1	2	1	1	1	1	
	NO= 11	NO= 12	NO= 13	NO= 14	NO= 15	NO= 16	NO= 17	NO= 18	NO= 19	NO= 20	
	.99988842	.97449088	.96348161	.94497073	.99999976	.99615681	.99956787	.99993086	.99977648	.99960947	
	2	1	1	63	4	23	25	4	25	7	
	NO= 21	NO= 22	NO= 23	NO= 24	NO= 25	NO= 26	NO= 27	NO= 28	NO= 29	NO= 30	
	.99977684	.99958611	.99610150	.99998122	.99999642	.99777043	.99992418	.99999881	.99815327	.99998498	
	4	7	7	21	4	4	4	4	46	21	
	NO= 31	NO= 32	NO= 33	NO= 34	NO= 35	NO= 36	NO= 37	NO= 38	NO= 39	NO= 40	
	.99999714	.99999374	.99933058	.99999881	.99976349	.99997544	.99999976	.89382303	.90146803	.79994559	
	4	21	4	4	4	4	4	4	4	6	
	NO= 41	NO= 42	NO= 43	NO= 44	NO= 45	NO= 46	NO= 47	NO= 48	NO= 49	NO= 50	
	.47519088	.99665731	.99122220	.99881530	.99925256	.99998772					
	20	20	20	59	2	2					

EQUIPMENT RESULTS

PROV. PROB.	PART OR PART TYPE PROV. PROB. AND THE ASSOCIATED NUMBER OF SPARES										TOTAL SPARES
	NO= 1	NO= 2	NO= 3	NO= 4	NO= 5	NO= 6	NO= 7	NO= 8	NO= 9	NO= 10	
.53941774	.99962622	.99983263	.99983263	.99998271	.99999440	.99777043	.99997044	.97604644	.98829687	.99590266	2
	0	0	0	0	0	0	0	0	0	0	
	NO= 11	NO= 12	NO= 13	NO= 14	NO= 15	NO= 16	NO= 17	NO= 18	NO= 19	NO= 20	
	.99983842	.97440088	.96348161	.94497073	.99999976	.99615681	.99956787	.99993086	.99977648	.99960947	
	0	0	0	0	0	0	0	0	0	0	
	NO= 21	NO= 22	NO= 23	NO= 24	NO= 25	NO= 26	NO= 27	NO= 28	NO= 29	NO= 30	
	.99977684	.99958611	.99610150	.99998122	.99999642	.99777043	.99992418	.99999881	.99815327	.99998498	
	0	0	0	0	0	0	0	0	0	0	
	NO= 31	NO= 32	NO= 33	NO= 34	NO= 35	NO= 36	NO= 37	NO= 38	NO= 39	NO= 40	
	.99999714	.99999374	.99933058	.99999881	.99976349	.99997544	.99999976	.89382303	.90146863	.97850269	
	0	0	0	0	0	0	0	0	0	1	
	NO= 41	NO= 42	NO= 43	NO= 44	NO= 45	NO= 46	NO= 47	NO= 48	NO= 49	NO= 50	
	.82875180	.99665731	.99122220	.99881530	.99925256	.99998772					
	1	0	0	0	0	0					

.62[illegible]

NO= 1	NO= 2	NO= 3	NO= 4	NO= 5	NO= 6	NO= 7	NO= 8	NO= 9	NO= 10
.99962872	.99983263	.99983263	.99998271	.99999440	.99777043	.99997044	.97604644	.98829687	.99590266
0	0	0	0	0	0	0	0	0	0
NO= 11	NO= 12	NO= 13	NO= 14	NO= 15	NO= 16	NO= 17	NO= 18	NO= 19	NO= 20
.99988842	.97440088	.76348161	.94497073	.99999976	.99615681	.99956787	.99993086	.99977648	.99960947
0	0	0	0	0	0	0	0	0	0
NO= 21	NO= 22	NO= 23	NO= 24	NO= 25	NO= 26	NO= 27	NO= 28	NO= 29	NO= 30
.99977684	.99958611	.99610150	.99996122	.99999642	.99777043	.99992418	.99999881	.99815327	.99998498
0	0	0	0	0	0	0	0	0	0
NO= 31	NO= 32	NO= 33	NO= 34	NO= 35	NO= 36	NO= 37	NO= 38	NO= 39	NO= 40
.99999714	.99999374	.99933058	.99999881	.99976349	.99997544	.99999976	.89382303	.90146863	.97850269
0	0	0	0	0	0	0	0	0	1
NO= 41	NO= 42	NO= 43	NO= 44	NO= 45	NO= 46	NO= 47	NO= 48	NO= 49	NO= 50
.96028274	.99665731	.99122220	.99881530	.99925256	.99998772				
2	0	0	0	0	0				

3

.6951 0.59

NO= 1	NO= 2	NO= 3	NO= 4	NO= 5	NO= 6	NO= 7	NO= 8	NO= 9	NO= 10
.99962622	.99983263	.99983263	.99978271	.99999440	.99777043	.99997044	.97604644	.98829687	.99590266
0	0	0	0	0	0	0	0	0	0
NO= 11	NO= 12	NO= 13	NO= 14	NO= 15	NO= 16	NO= 17	NO= 18	NO= 19	NO= 20
.99988842	.97440088	.96348161	.94497073	.99999976	.99615681	.99956787	.99993086	.99977648	.99960947
0	0	0	0	0	0	0	0	0	0
NO= 21	NO= 22	NO= 23	NO= 24	NO= 25	NO= 26	NO= 27	NO= 28	NO= 29	NO= 30
.99977684	.99956611	.99610150	.99998122	.99999642	.99777043	.99992418	.99999881	.99815327	.99998498
0	0	0	0	0	0	0	0	0	0
NO= 31	NO= 32	NO= 33	NO= 34	NO= 35	NO= 36	NO= 37	NO= 38	NO= 39	NO= 40
.99999714	.99999374	.99933058	.99999881	.99976349	.99997544	.99999976	.99415243	.90146863	.97850269
0	0	0	0	0	0	0	1	0	1
NO= 41	NO= 42	NO= 43	NO= 44	NO= 45	NO= 46	NO= 47	NO= 48	NO= 49	NO= 50
.96028274	.99665731	.99122220	.99881530	.99925256	.99998772				
2	0	0	0	0	0				

4

.76729910

NO= 1	NO= 2	NO= 3	NO= 4	NO= 5	NO= 6	NO= 7	NO= 8	NO= 9	NO= 10
.99962622	.99983263	.99983263	.99998271	.99999440	.99777043	.99997044	.97604644	.98829687	.99590266
0	0	0	0	0	0	0	0	0	0
NO= 11	NO= 12	NO= 13	NO= 14	NO= 15	NO= 16	NO= 17	NO= 18	NO= 19	NO= 20
.99988842	.97440088	.96348161	.94497073	.99999976	.99615681	.99956787	.99993086	.99977648	.99960947
0	0	0	0	0	0	0	0	0	0
NO= 21	NO= 22	NO= 23	NO= 24	NO= 25	NO= 26	NO= 27	NO= 28	NO= 29	NO= 30
.99977684	.99958611	.99610150	.99998122	.99999642	.99777043	.99992418	.99999881	.99815327	.99998498
0	0	0	0	0	0	0	0	0	0
NO= 31	NO= 32	NO= 33	NO= 34	NO= 35	NO= 36	NO= 37	NO= 38	NO= 39	NO= 40
.99999714	.99999374	.99933058	.99999881	.99976349	.99997544	.99999976	.99415243	.99497795	.97850269
0	0	0	0	0	0	0	1	1	1
NO= 41	NO= 42	NO= 43	NO= 44	NO= 45	NO= 46	NO= 47	NO= 48	NO= 49	NO= 50
.96028274	.99665731	.99122220	.99881530	.99925256	.99998772				
2	0	0	0	0	0				

5

.83826953

NO= 1	NO= 2	NO= 3	NO= 4	NO= 5	NO= 6	NO= 7	NO= 8	NO= 9	NO= 10
.99962622	.99983263	.99983263	.99998271	.99999440	.99777043	.99997044	.97604644	.98829687	.99590266
0	0	0	0	0	0	0	0	0	0
NO= 11	NO= 12	NO= 13	NO= 14	NO= 15	NO= 16	NO= 17	NO= 18	NO= 19	NO= 20
.99988842	.97440088	.96348161	.99845749	.99999976	.99615681	.99956787	.99993086	.99977648	.99960947
0	0	0	1	0	0	0	0	0	0
NO= 21	NO= 22	NO= 23	NO= 24	NO= 25	NO= 26	NO= 27	NO= 28	NO= 29	NO= 30
.99977684	.99958611	.99610150	.99998122	.99999642	.99777043	.99992418	.99999881	.99815327	.99998498
0	0	0	0	0	0	0	0	0	0
NO= 31	NO= 32	NO= 33	NO= 34	NO= 35	NO= 36	NO= 37	NO= 38	NO= 39	NO= 40
.99999714	.99999374	.99933058	.99999881	.99976349	.99997544	.99999976	.99415243	.99497795	.97850269
0	0	0	0	0	0	0	1	1	1
NO= 41	NO= 42	NO= 43	NO= 44	NO= 45	NO= 46	NO= 47	NO= 48	NO= 49	NO= 50
.99290401	.99665731	.99122220	.99881530	.99925256	.99998772				
3	0	0	0	0	0				

7

.8920[illegible]

NO= 1	NO= 2	NO= 3	NO= 4	NO= 5	NO= 6	NO= 7	NO= 8	NO= 9	NO= 10
.99962622	.99983263	.99983263	.99998271	.99999440	.99777043	.99997044	.97604644	.98829667	.99590266
0	0	0	0	0	0	0	0	0	0
NO= 11	NO= 12	NO= 13	NO= 14	NO= 15	NO= 16	NO= 17	NO= 18	NO= 19	NO= 20
.99988842	.99960949	.99932486	.99845749	.99999976	.99615681	.99956787	.99993086	.99977648	.99960947
0	1	1	1	0	0	0	0	0	0
NO= 21	NO= 22	NO= 23	NO= 24	NO= 25	NO= 26	NO= 27	NO= 28	NO= 29	NO= 30
.99977684	.99958611	.99610150	.99998122	.99999642	.99777043	.99992418	.99999891	.99815327	.99998498
0	0	0	0	0	0	0	0	0	0
NO= 31	NO= 32	NO= 33	NO= 34	NO= 35	NO= 36	NO= 37	NO= 38	NO= 39	NO= 40
.99999714	.99999374	.99933058	.99999881	.99976349	.99997544	.99999976	.99415243	.99497795	.97850269
0	0	0	0	0	0	0	1	1	1
NO= 41	NO= 42	NO= 43	NO= 44	NO= 45	NO= 46	NO= 47	NO= 48	NO= 49	NO= 50
.99290401	.99665731	.99122220	.99681530	.99925256	.99598772				
3	0	0	0	0	0				

9

.91362822	NO= 1	NO= 2	NO= 3	NO= 4	NO= 5	NO= 6	NO= 7	NO= 8	NO= 9	NO= 10	10
	.99962622	.99983263	.99983263	.99998271	.99999440	.99777043	.99997044	.99971074	.99829687	.99590266	
	0	0	0	0	0	0	0	1	0	0	
	NO= 11	NO= 12	NO= 13	NO= 14	NO= 15	NO= 16	NO= 17	NO= 18	NO= 19	NO= 20	
	.99989842	.99966949	.99932486	.99845749	.99999976	.99615681	.99956787	.99993086	.99977648	.99960947	
	0	1	1	1	0	0	0	0	0	0	
	NO= 21	NO= 22	NO= 23	NO= 24	NO= 25	NO= 26	NO= 27	NO= 28	NO= 29	NO= 30	
	.99977684	.99958611	.99610150	.99998122	.99999642	.99777043	.99992418	.99999881	.99815327	.99998498	
	0	0	0	0	0	0	0	0	0	0	
	NO= 31	NO= 32	NO= 33	NO= 34	NO= 35	NO= 36	NO= 37	NO= 38	NO= 39	NO= 40	
	.99999714	.99999374	.99933058	.99999881	.99976349	.99997544	.99999976	.99415243	.99497795	.97850269	
	0	0	0	0	0	0	0	1	1	1	
	NO= 41	NO= 42	NO= 43	NO= 44	NO= 45	NO= 46	NO= 47	NO= 48	NO= 49	NO= 50	
	.99290401	.99665731	.99122220	.99881530	.99925256	.99998772					
	3	0	0	0	0	0					

TABLE 4-2B

.93196306	NO= 1	NO= 2	NO= 3	NO= 4	NO= 5	NO= 6	NO= 7	NO= 8	NO= 9	NO= 10
	.99999988	********	********	********	.99999994	.99999750	********	.99971074	.99993122	.99999160
	1	1	1	1	1	1	1	1	1	1
	NO= 11	NO= 12	NO= 13	NO= 14	NO= 15	NO= 16	NO= 17	NO= 18	NO= 19	NO= 20
	********	.99966949	.99932486	.99845749	.99999976	.99615681	.99956787	.99993086	.99977648	.99960947
	1	1	1	1	0	0	0	0	0	0
	NO= 21	NO= 22	NO= 23	NO= 24	NO= 25	NO= 26	NO= 27	NO= 28	NO= 29	NO= 30
	.99977684	.99958611	.99610150	.99998122	.99999642	.99777043	.99992418	.99999881	.99815327	.99998498
	0	0	0	0	0	0	0	0	0	0
	NO= 31	NO= 32	NO= 33	NO= 34	NO= 35	NO= 36	NO= 37	NO= 38	NO= 39	NO= 40
	.99999714	.99999374	.99933058	.99999881	.99976349	.99997544	.99999976	.99415243	.99497795	.97850269
	0	0	0	0	0	0	0	1	1	1
	NO= 41	NO= 42	NO= 43	NO= 44	NO= 45	NO= 46	NO= 47	NO= 48	NO= 49	NO= 50
	.99290401	.99665731	.99122220	.99881530	.99925256	.99998772				
	3	0	0	0	0	0				

20

TABLE 4.3A

RECOMMENDED SPARES WITHOUT CRITICAL COMPONENT CONSIDERATIONS

PROVISIONING PERIOD	No. of Spares								
	1 Month			3 Months			6 Months		
DESIRED PROTECTION LEVEL	.90	.95	.99	.90	.95	.99	.90	.95	.99
COMPONENT									
Intensity Selswitch	0	0	0	0	0	1	0	0	1
kr549848vdc auto cntl relay	0	0	0	0	0	0	0	0	0
kr549848vdc low entl relay	0	0	0	0	0	0	0	0	0
at-15 master (asr) photocel	0	0	0	0	0	0	0	0	0
1060ieelb master (asr) pulsar	0	0	0	0	0	0	0	0	0
q0260 48 volt p-s ckt brea	0	0	1	0	1	1	1	1	1
48 volt p-s transformer	0	0	0	0	0	0	0	0	0
au-5894 48 volt pwr supp	1	1	1	1	1	2	1	2	2
626 1b 0-20 volt pwr supp	1	1	1	1	1	1	1	1	2
620.24e 24 volt pwr supp	0	0	1	1	1	1	1	1	1
91760-002 master transcei	0	0	0	0	0	0	0	0	0
20-20 override switch	1	1	1	1	1	2	1	2	2
fusetron 2a for 48 volt psfuse	1	1	1	1	2	2	2	2	3
q6.6par562 runway lamps lamp	1	1	2	2	2	2	2	3	3
rem-hdwe sel. switch	0	0	0	0	0	0	0	0	0
kr549848vdc aux pilot relay	0	0	1	0	1	1	1	1	1
pbtb-365 .5microfarad capacito	0	0	0	0	0	1	0	0	1
at-15 remote photocel	0	0	0	0	0	0	0	0	0
100-, 2 watt resister	0	0	0	0	0	0	0	0	1
kaa20 lamp p-s fuse	0	0	0	0	0	1	0	0	1
kaa20 remote lamp fuse	0	0	0	0	0	0	0	0	1
w10g2 lamp p-s variae	0	0	0	0	0	1	0	0	1
prdllay0 hi-lo sel relay	0	0	1	0	1	1	1	1	1
prdllay0 power relay	0	0	0	0	0	0	0	0	0
prdllay0 remote power relay	0	0	0	0	0	0	0	0	0
prdllay0 remote hi-lo relay	0	0	1	0	1	1	1	1	1
prdllay0 pulsar pwr relay	0	0	0	0	0	0	0	0	0
1060ieelb remote pulsar	0	0	0	0	0	0	0	0	0
mov-130v surpress	0	0	1	0	0	1	1	1	1
cub51-70120 timer relays	0	0	0	0	0	0	0	0	0
cub51-70120 remote timer relays	0	0	1	0	0	0	0	0	0
112xax1195 monitor relays	0	0	0	0	0	0	0	0	0
kupl1a15120v remote aux, relay	0	0	0	0	0	1	0	0	1
112xax595 rem monitor relay	0	0	0	0	0	0	0	0	0
w8g2 remote variae	0	0	0	0	0	0	0	0	1
remote power switch	0	0	0	0	0	0	0	0	0
twr-microwave switch	0	0	0	0	0	0	0	0	0
300-33086 microwave detector	1	1	2	2	2	3	3	3	4
91760-002 remote transcei	1	1	2	2	2	3	3	3	4
20-20 runway act switch	1	2	3	3	3	4	4	5	6
20-20 departure actswitch	3	3	4	6	7	8	10	11	12
156-14c100 twr control relay	0	0	1	0	1	1	1	1	1
a43-01a twr timer relay	0	1	1	1	1	1	1	1	2
1n3613 diode	0	0	1	0	0	1	0	1	1
rem-pri sel switch	0	0	0	0	0	1	0	0	1
rem pri act. switch	0	0	0	0	0	0	0	0	0

TABLE 4.3B

RECOMMENDED SPARES WITH CRITICAL COMPONENT CONSIDERATION

PROVISIONING PERIOD	No. of Spares: 1 Month			3 Months			6 Months		
ACHIEVED PROTECTION LEVEL	.93	.96	.992	.91	.96	.993	.91	.96	.993
COMPONENT									
Intensity Selswitch	1	1	1	1	1	1	1	1	1
kr549848vdc auto cntl relay	1	1	1	1	1	1	1	1	1
kr549848vdc low entl relay	1	1	1	1	1	1	1	1	1
at-15 master (asr) photocel	1	1	1	1	1	1	1	1	1
1060leelb master (asr) pulsar	1	1	1	1	1	1	1	1	1
q0260 48 volt p-s ckt breaker	1	1	1	1	1	1	1	1	1
48 volt p-s transformer	1	1	1	1	1	1	1	1	1
au-5894 48 volt pwr supp	1	1	1	1	1	2	1	2	2
62063b 0-20 volt pwr supp	1	1	1	1	1	1	1	1	2
62024e 24 volt pwr supp	1	1	1	1	1	1	1	1	1
91760-002 master transcei	1	1	1	1	1	1	1	1	1
20-20 override switch	1	1	1	1	1	2	1	2	2
fusetron 2a for 48 volt psfuse	1	1	1	1	2	2	2	2	3
q6.6par562 runway lamps lamp	1	1	2	2	2	2	2	3	3
rem-hdwe sel. switch	0	0	0	0	0	0	0	0	0
kr549848vde aux pilot relay	0	0	1	0	1	1	1	1	1
phtb-365 .5microfarad capacito	0	0	0	0	0	1	0	0	1
at-15 remote photocel	0	0	0	0	0	0	0	0	0
100-, 2 watt resister	0	0	0	0	0	0	0	0	1
kaa20 lamp p-s fuse	0	0	0	0	0	1	0	0	1
kaa20 remote lamp fuse	0	0	0	0	0	0	0	0	1
w10µ2 lamp p-s variae	0	0	0	0	0	1	0	0	1
prdllay0 hi-lo sel relay	0	0	1	0	1	1	1	1	1
prdllay0 power relay	0	0	0	0	0	0	0	0	0
prdllay0 remote power relay	0	0	0	0	0	0	0	0	0
prdllay0 remote hi-lo relay	0	0	1	0	1	1	1	1	1
prdllay0 pulsar pwr relay	0	0	0	0	0	0	0	0	0
1060leelb remote pulsar	0	0	0	0	0	0	0	0	0
mov-130v surpress	0	0	1	0	0	1	0	1	1
cub51-70120 timer relays	0	0	0	0	0	0	0	0	0
cub51-70120 remote timer relays	0	0	1	0	0	0	0	0	0
112xax1195 monitor relays	0	0	1	1	0	0	0	0	0
kupll3l5120v remote aux, relay	0	0	0	0	0	1	0	0	1
112xax595 rem monitor relay	0	0	0	0	0	0	0	0	0
w8µ2 remote variae	0	0	0	0	0	0	0	0	1
remote power switch	0	0	0	0	0	0	0	0	0
tmr-microwave switch	0	0	0	0	0	0	0	0	0
300-33086 microwave detector	1	1	2	2	2	3	3	3	4
91760-002 remote transcei	1	1	2	2	2	3	3	3	4
20-20 runway act switch	1	2	3	3	3	4	4	5	6
20-20 departure actswitch	3	3	4	6	7	8	10	11	12
156-14c100 twr control relay	0	0	1	0	1	1	1	1	1
a41-01a twr timer relay	0	1	1	1	1	1	1	1	2
1n3613 diode	0	0	0	0	0	1	0	1	1
rem-pri sel switch	0	0	0	0	0	1	0	0	1
rem-pri act. switch	0	0	0	0	0	0	0	0	0

APPENDIX D

STRUTHERS-DUNN PROGRAM DIRECTOR MODEL 3001 ENVIRONMENTAL TESTS

(This document was reprinted in its entirety
for presentation in this appendix.)

Project No. 143-152-300
Report No. 80-21
February 8, 1980
Struthers-Dunn
Program Director
Model 3001
Environmental Tests

General:

This report presents the results of functional tests of one Struthers-Dunn Program Director, Model 3001, during and following exposures to temperature and humidity extremes. The tests were requested by Mr. Bret B. Castle, ANA-410.

Material Submitted:

1. One Program Director, Model 3001, manufactured by Struthers-Dunn Company.

2. One test assembly, consisting of 21 small incandescent lamps with 21 corresponding activate switches and one override switch.

3. One 48 volt power supply.

Test Sequence:

The following test sequence was performed by Mr. Michael Petri, ANA-410, at appropriate times to assess the performance of the Program Director, Model 3001, while subjected to the test environments.

1. Light nos. 1, 2 and 3 were activated and then timed out, thus checking that the clocks and counter resets were functioning properly.

2. Lights 4, 5 and 6 were activated, then override was pressed; thus turning all lights off. This demonstrated that the override function worked properly by turning off all lights and resetting the counters.

3. Lights 7, 8 and 9 were activated and timed out.

4. Lights 10, 11 and 12 were activated and then reset.

5. Lights 13, 14 and 15 were activated and timed out.

6. Lights 16, 17 and 18 were activated and then reset.

7. Lights 18 and 19 were turned on, then switches 20 and 21 were pressed to make sure the lockout feature was operating. Then another light was pressed to make certain the lockout feature only locked out lights 20 and 21.

8. Lights 20 and 21 were turned on, then switches 18 and 19 were pressed to make sure the lockout feature worked properly. Another light was pressed to make certain only lights 18 and 19 were locked out.

9. The 48 volt power supply was turned off, then back on, to insure that the automatic reset was working.

10. Many switches were pressed to check that only three lights could be turned on at any one time.

11. Light no. 2, showing the 20 second countdown, was activated to check the liquid crystal display for legibility.

Test Methods and Results:

On January 31, 1980, the "Director" was placed in a Tenney Engineering Environmental Chamber, Model 27STR-50206, and the test sequence performed at room ambient temperatures. Power was then shut off on the "Director" and the chamber temperature lowered to -12°C, until the test unit temperature reached -10°C (2-1/2 hours) and the chamber temperature then held at -10°C for an additional hour. Test sequence was then run within 15 minutes of applying power to the "Director."

Following the tests at -10°C, the chamber temperature was increased with power applied to the "Director" and its temperature monitored. The test sequence was repeated at 0°C, 10°C, 20°C, 30°C, and 40°C. The test unit and chamber were then turned off and allowed to return to room ambient conditions for 3 days.

On February 4, 1980, all sources of moisture in the chamber, including the chamber wet bulb instrumentation, were closed off. The "Director" was turned on and the chamber temperature raised to 50°C, with the chamber "breathing" room ambient air. The test sequence was performed seven times at hourly intervals during the day, and again at 0830 on February 5. From dewpoint and wet and dry bulb measurements of the room ambient air over the period, the relative humidity in the chamber was calculated as approximately 3 percent.

On February 5, following the test sequence, the "Director" was turned off and the humidity instrumentation and controls for the chamber turned on. The relative humidity, as indicated by wet and dry bulb temperature differential sensors, was maintained at an average of 93 percent with excursion between 92.5 percent and 98.5 percent, for 24-1/2 hours at 50°C.

On February 6, at 1100, the "Director" was turned on and the test sequence performed. The chamber was then shut off and opened to room air for an hour and a half. The chamber was then closed and the temperature of the "Director" dropped to -17.7°C, and the test sequence performed at 1516. The chamber was then allowed to return to room ambient conditions overnight and the equipment returned to ANA-410 for further operation.

The "Director" worked properly during all performances of the test sequence. At low temperature, the liquid crystal display was sluggish in the transitions of its active segments; the 1/10 second digit being practically undistinguishable for some observers, and the tens of seconds digit distinguishable but not sharp in contrast against the background.

Report prepared by: Frank J. Bain
Frank J. Bain, ANA-151

Checked by: Bret Castle

Approved by: Chas. M. Daniel