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Failure Modes, Effects and Criticality Analysis (FMECA) of Type AN/GRN-27 (V) Instrument Landing System With Traveling-Wave Localizer Antenna

Pailen-Johnson Associates, Inc.
7655 Old Springhouse Road
McLean, Virginia 22102

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February 1983

Final Report

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16. Abstract

A Failure Modes, Effects and Criticality Analysis (FMECA) is used to determine, for the AN/GRN-27(V), the probability of radiation of a hazardous signal and the probability of a loss of signal. This analysis is based on the FMECA performed on the Texas Instruments, Incorporated Mark III ILS (Report No. FAA-RD-73-111), modified to reflect the differences between the Mark III and the GRN-27. The methodology considers the effects of all failures of functionally distinct circuits which can result in potentially hazardous failure modes.

Possible modifications to operating procedures and equipment are considered with respect to meeting the proposed Level 3 and Level 4 reliability levels. The reliability resulting from such improvements is calculated and a description of recommended improvements is included.

Facility Maintenance Logs for the calendar year 1981 from GRN-27 facilities are analyzed and correlated with the theoretical calculations.

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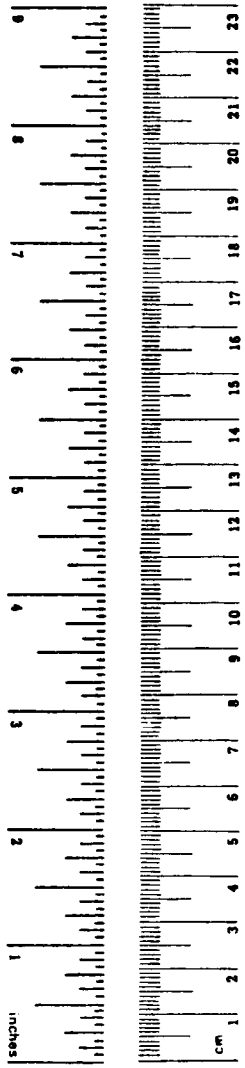
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

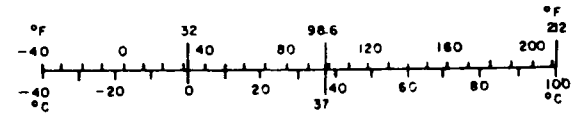
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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 (exactly). 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

Symbol	When You Know	Multiply by	To Find	Symbol
		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



60 mph = 52.1 knots (nautical miles per hour)
60 mph = 88'/sec 1g = 32.2'sec^2

1 mph = .87 knots
1 knot - 1.15 mph

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1.0 INTRODUCTION

Pailen-Johnson Associates, Inc. has performed a detailed reliability analysis of the Type AN/GRN-27(V) Instrument Landing System (ILS) or Type II ILS manufactured by Texas Instruments, Inc. This system is commonly designated the GRN-27, which will also be used in this report. The system transmits signals which provide landing guidance for approaching aircraft. The reliability analysis was performed to determine the probability of radiation of a hazardous signal and the probability of a system shutdown during the critical final stages of a landing. Also, a number of system modifications which could be implemented to improve reliability were evaluated.

The objective of the study was to establish whether the GRN-27 ILS could satisfy the reliability guidelines expected to be established by the International Civil Aviation Organization (ICAO) for an ILS which is to be used during limited visibility conditions (Category III). Those guidelines specify that the probability of hazardous radiation due to equipment failure should be less than 0.5×10^{-9} for the localizer or the glideslope during any landing sequence and the probability of localizer or glideslope shutdown should be less than 2.0×10^{-6} during the critical final stages of a landing sequence. Although these guidelines are not strict requirements, it is likely that the United States and most other ICAO member nations will attempt to meet them.

The reliability analysis was based upon a study of another system, designated the Mark III ILS, which was built using many of the same sub-assemblies contained in the GRN-27 but also incorporates more extensive monitoring and higher levels of redundancy. Texas Instruments manufactured the Mark III System and performed the reliability study of the system. The analysis consisted of identifying all the failure modes of each subassembly in the ILS and computing the rate of failure for each mode. The subassembly failure modes were then considered alone and in combination to determine how the system as a whole could fail. For each such system failure mode, the probability of failure was computed. Finally, the probability of hazardous radiation and of a system shutdown were computed. As currently operated, the computed probability of an undetected hazardous radiation occuring between system checks is

8.75×10^{-8} for the localizer and approximately 8.7×10^{-8} for all versions of the glideslope. The probability of a system shutdown is 1.81×10^{-7} for the localizer (during a 30 second critical period), and approximately 6.25×10^{-8} for all versions of the glideslope (for a 15 second period).

Since the GRN-27 ILS as currently operated does not meet the hazardous radiation guidelines specified above, various changes in the system and/or operating system have been considered to improve its reliability. A previous effort by Texas Instruments to produce an ILS suitable for all weather landings resulted in the Mark III ILS. Only a few of the Mark III systems were produced. Although they satisfy the ICAO reliability guidelines, it would be prohibitively expensive to modify the GRN-27 units to be the same as the Mark III systems.

Of all the alternatives considered to improve the reliability of the GRN-27, one appears to be the most cost-effective. That alternative consists of more frequent tests for hidden failures. The tests can be performed by introducing a simulated fault into the monitoring system and determining whether the system transfers to the standby transmitter. Such a fault could be introduced using relays which have been built into the monitor channels for that purpose. However, if it would be desirable to activate these relays from the control tower, conductors would have to be laid from the ILS equipment shelter to the tower if none are available. The check would have to be performed approximately once a day to achieve the level of reliability specified by the ICAO guidelines.

An effort was made to correlate actual field experience with the theoretical failure calculations. To this end the facility maintenance logs from sixty-nine GRN-27 facilities for the calendar year 1981 were analyzed and the unscheduled outages recorded were compared with the theoretical calculations. The field experience was consistent with the theoretical results. Also, the recorded outages revealed problem areas in the ILS equipment. Peak detector failures, in particular, accounted for a relatively large number of outages. Improvements in the transmitter and removal of the localizer misalignment detectors could also eliminate some outages.

2.0 ILS RELIABILITY REQUIREMENTS

Standards and Recommended Practices (SARP's), and guidance material have been developed by the ICAO for navigation aids, including ILS. For the purpose of describing reliability criteria and relating them to different levels of performance, the following ILS facility performance categories are defined (Reference 1):

Category I - Provides guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the glide path at a height of 200 feet or less above the horizontal plane containing the threshold.

Category II - Provides guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the glide path at a height of 50 feet or less above the horizontal plane containing the threshold.

Category III - With the aid of ancillary equipment where necessary, provides guidance information from the coverage limit of the facility to, and along, the surface of the runway.

Each ILS Facility Performance Category has operational objectives as follows (Reference 1, Attachment C):

Category I - Operation down to 200 feet decision height with a runway visual range of not less than a value of the order of 2600 feet with a high probability of approach success.

Category II - Operation down to 100 feet decision height and with a runway visual range of not less than a value of the order of 1200 feet with a high probability of approach success.

Category IIIA - Operation with no decision height limitation to and along the surface of the runway with external visual reference during the final phase of landing and with a runway visual range of not less than a value of the order of 700 feet.

Category IIIB - Operation with no decision height limitation to and along the surface of the runway without reliance on external visual reference; and, subsequently, taxiing with external visual reference in a visibility corresponding to a runway visual range of not less than a value of the order of 150 feet.

Category IIIC - Operation with no decision height limitation to and along the surface of the runway and taxiways without reliance on external visual reference.

These operational objectives are intended for "guidance and clarification" only and are not part of the ICAO SARP's. However, these objectives are widely accepted as standards for ILS operation.

Reliability objectives are also specified in Reference 1, Attachment C. The objectives consist, in part, of the following:

<u>Category II and III</u>

- "...it is of upmost importance that the integrity and continuity of services of the ground equipment is very high."

- The monitors should be designed to ensure fail safe operation.

Category III

- "Reliability of ground equipment must be very high, so as to ensure that safety during the critical phase of approach and landing is not impaired by a ground equipment failure when the aircraft is at such a height or attitude that it is unable to take corrective action".

- "One analysis has shown that the continuity of service of an ILS installation used for Category IIIA operation should be such that the localizer facility and the glide path facility each have a MTBF of 4000 hours or more."

Additional reliability objectives specified in reference are also expressed in general terms.

In an effort to establish more specific reliability objectives for ILS equipment, the All Weather Operations Panel (AWOP) of the ICAO proposed a set of reliability levels in December of 1982. The levels are specified, in part, in terms of the probability of hazardous radiation during any one landing (signal integrity), the probability of a system shutdown during the critical landing time interval (signal continuity), and mean time between operational outages (MTBO). Table 2-1 shows the proposed requirements for each reliability level of the localizer or glide path.

Table 2-1

PROPOSED RELIABILITY LEVELS

Proposed Level Designation	Probability of Hazardous Radiation in any One Landing	Probability of a Shutdown During Indicated Interval	MTBO (hours)
Level 1	Not Defined	Not Defined	Not Defined
Level 2	1.0×10^{-6}	4.0×10^{-6} (15 sec)	1000
Level 3	0.5×10^{-9}	2.0×10^{-6} (15 sec)	2000
Level 4	0.5×10^{-9}	2.0×10^{-6} (loc-30 sec) (gp -15 sec)	4000 (loc) 2000 (gp)

These reliability levels are likely to be accepted as general guidelines for Operational Performance Usage with Level 1 applying to Category I, Level 2 to Category II, Level 3 to Category IIIA, Level 4 to Category IIIB and IIIC. The proposed set of levels has not yet been accepted by ICAO. However, acceptance is expected with few, if any changes.

The following new tentative guidance material, essentially as proposed by AWOP partially describes the conditions as understood to be applicable to the numbers proposed in Table 2-1.

- An integrity failure can occur if radiation of a signal is either unrecognized by the monitoring equipment or the control circuits fail to remove the faulty signal. Such a failure might constitute a hazard if it results in a gross error.

- Clearly, not all integrity failures are hazardous in all phases of the approach. For example, during the final critical stages of the approach, undetected failures producing gross errors in course width or course line shifts are of special significance, whereas an undetected change in modulation depth, or loss of localizer and glideslope clearance, and localizer identification would not necessarily produce a hazardous situation. The criterion in assessing which failure modes are relevant must however include all those fault conditions which are not unquestionably obvious but are deleterious to the automatic flight system or the pilot.

- With regard to integrity, since the probability of occurrence of an unsafe failure within the monitoring or control equipment is extremely remote, to establish the required integrity level with a high degree of confidence would necessitate an evaluation period many times that needed to establish the equipment MTBF. Such a protracted period is unacceptable and therefore the required integrity level can only be predicted by rigorous design analysis of the equipment.

- The MTBF of equipment is governed by basic construction and operating environment. Equipment design should employ the most suitable engineering techniques, materials and components, and rigorous inspection should be applied during manufacture. It is essential to ensure that equipment is operated within the environmental conditions specified by the manufacturer. The manufacturer should be requested to provide the details of the design to enable the MTBF and continuity of service to be calculated. It is recommended that the equipment MTBF should be confirmed by evaluation in an operational environment to take account of the impact of operational factors, i.e., airport environment, inclement weather conditions, power availability, quality and frequency of maintenance, etc. For integrity and continuity of service levels 2, 3 or 4, the evaluation period should be sufficient to determine achievement of the required level with a high degree of confidence.

- Continuity of service performance may be demonstrated by means of MTBO (Mean Time Between Outages) where an outage is defined as any unanticipated cessation of signal-in-space. It is calculated by dividing the total facility up-time by the number of operational failures. MTBF and MTBO are not always equivalent, as not all equipment failures will necessarily result in an outage, eg., an event such as a failure of a transmitter resulting in the immediate transfer to a standby transmitter. The minimum MTBO values expected for the continuity of service have been derived from several years of operational experience of many systems. To determine whether the performance record of an individual ILS system justifies its assignment to level 2, 3 or 4 requires a judicious consideration of such factors as:

  1) the performance record and experience of system use established over a suitable period of time;

  2) the average achieved MTBO established for this type of ILS; and

  3) the trend of failure rates

  An assigned designation should not be subject to frequent change.

The GRN-27 ILS was manufactured by Texas Instruments to U.S. Department of Defense specifications, and has been used mainly for Category II Operations. A few Mark III ILS units were also manufactured by Texas Instruments. Those units utilize many of the same subassemblies as the GRN-27 but incorporate more extensive monitoring and higher levels of redundancy. The TI Mark III ILS was built to U.S. Federal Aviation Administration (FAA) specifications at a time when ICAO reliability guidelines were general in nature and long before the minimums shown in Table 2-1 were proposed.

With little ICAO guidance, the FAA set reliability requirements on the TI Mark III System with the goal that the use of the ILS would be as safe as a person can predictably expect to be in day-to-day activities (Reference 2). Those requirements were as follows: The theoretical probability of a potentially hazardous signal fault, including loss of signal, during any 10-second period for the localizer and any 5-second period for the glide slope, should not exceed 1.0×10^{-7} due to equipment failure. The results of a failure modes, effects and criticality analysis of the TI Mark III ILS show that the system meets the FAA reliability requirements (Reference 3). As will be shown in Section 5, the TI Mark III ILS also meets the standards set for all categories in Table 2-1.

There is currently a requirement to qualify many of the U.S. GRN-27 ILS installations for Category III operational status. As will be shown in Section 5, as currently operated, the GRN-27 ILS will not meet the Category III reliability limits in Table 2-1. Assuming that the standards set in Table 2-1 are adopted, the GRN-27 will either have to be replaced or modified to meet these standards.

3.0 SYSTEM DESCRIPTION

The GRN-27 ILS consists of a localizer station which provides horizontal guidance, a glideslope station which provides vertical guidance, and a remote control unit which displays the system status and provides remote control of the system. An ILS installation may also include distance measuring equipment (DME) and up to three marker beacons; however, DME and marker beacons are not included in this analysis, and, therefore, will not be described.

3.1 LOCALIZER

3.1.1 LOCALIZER SIGNAL DESCRIPTION

Each localizer is operated at a station frequency which is selected from the range of 108.1 to 111.95 MHz. The localizer station radiates signals at two slightly different frequencies. A course signal, with a carrier frequency 4.75 KHz above the assigned station frequency is radiated in a relatively narrow beam pattern. The course signal provides guidance on or near the approach centerline. A clearance signal, with a carrier frequency 4.75 KHz below the assigned station frequency is radiated at lower power over a larger sector. This clearance signal provides guidance to the narrow sector centered on the course centerline where the course signal can be acquired. The ccurse and clearance beam patterns are depicted in Figure 3-1.

A single detector in an aircraft detects both the course and clearance signals, responding only to the stronger course signal near the centerline, and responding only to the clearance signal some distance from the centerline. This type of operation is called a two frequency capture-effect system. Both course and clearance signals contain 90 and 150 Hz modulation components combined in the equipment and in the field to produce a predominance of 90 Hz modulation to the left of the runway centerline and a predominance of 150 Hz modulation to the right of the centerline (as viewed from the approach end of the runway). On the centerline the 90 and 150 Hz modulation components are equal in strength.

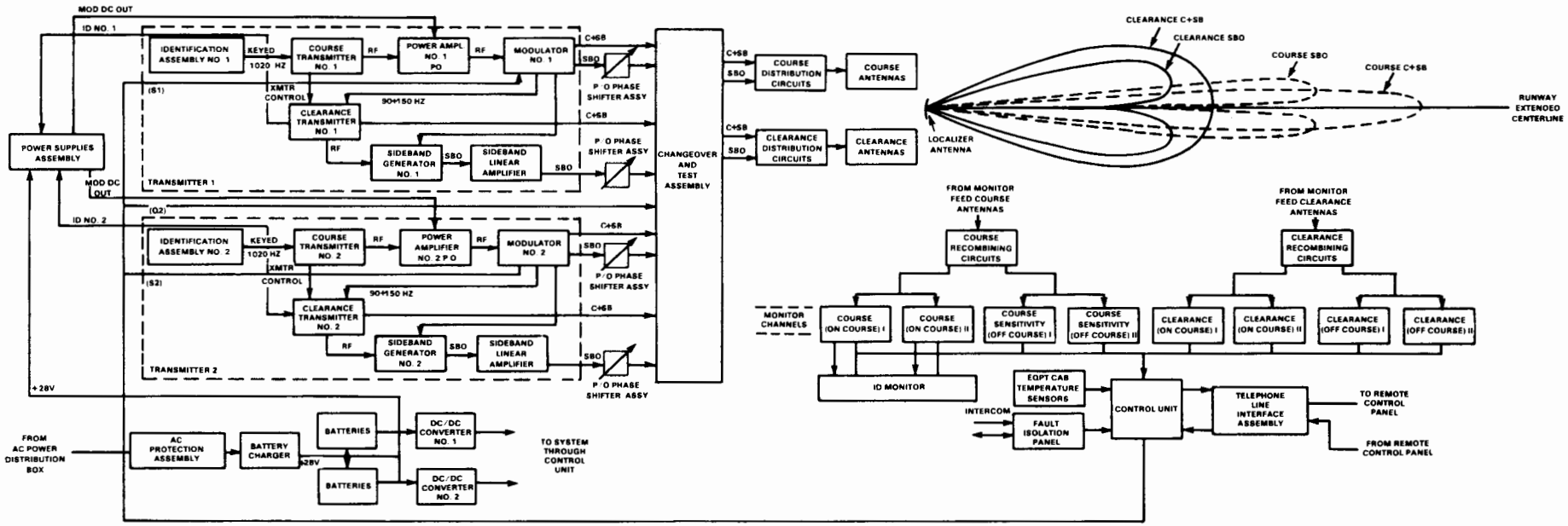


Figure 3.1. Localizer Station, Functional Block Diagram

The localizer course and clearance signals are formed using the same technique. The carrier is modulated by 90 and 150 Hz tones, producing a signal with the following frequency components: C, C+90, C-90, C+150, C-150; where C is the carrier frequency. A signal with all five frequency components, referred to as carrier plus sidebands or C+SB, is radiated in a beam with maximum signal strength on the course centerline, as depicted in Figure 3-1. Another signal is formed without the carrier frequency, referred to as sidebands only or SBO, and is radiated in a double beam pattern with a null on the centerline, also depicted in Figure 3-1.

In the SBO signal, each frequency component in one of the two beams is 180° out of phase with the same frequency components in the other beam. Further, the signals fed to the antenna elements are adjusted such that C+90 and C-90 signals in the left SBO beam are in phase with those signals in the C+SB, while the C+150 and C-150 signals in the left SBO beam are 180° out of phase with those signals in the C+SB. Therefore, the 90 Hz sidebands in the C+SB and SBO on the left combine to produce a weaker signal. Similarly, on the right the 150 Hz sidebands combine to produce a stronger signal than the combined 90 Hz sidebands.

The differences between the 90 and 150 Hz modulation components is positive on one side of the centerline, negative on the other side and increases in magnitude with angular displacement from the centerline. The difference is therefore used in aircraft to provide angular guidance. Specifically, airborne equipment computes the difference between the two modulation components divided by the carrier signal level. This computed quantity, called the difference in depth of modulation (DDM), is displayed showing the angular position of the aircraft with respect to the centerline. The airborne equipment also computes the sum of the two modulation components divided by the carrier signal level, called the sum of depth of modulation (SDM). This is computed to ensure that the total modulation of the radiated signal is adequate, and, if it is not, an indicator is displayed prohibiting use of the signal for guidance. The RF power level is similarly monitored to ensure adequate signal strengths.

An identification unit, which provides the pilot with identification of the localizer, generates a 1020 Hz Morse Code identification signal which modulates both the course and clearance carriers.

3.1.2 LOCALIZER FUNCTIONAL DESCRIPTION

As indicated in Figure 3-1, the localizer contains two identical transmitter systems, either of which can be designated as "main" while the other is "standby". Both transmitters are connected to the changeover and test assembly which channels signals from the operating transmitter to the antennas via the distribution circuits. During ordinary operations, the main transmitter provides the radiated signal while the standby transmitter is off.

The radiated signal is monitored by integral monitors and a far field monitoring system. Integral monitoring is accomplished by sampling the signal in each of the antenna radiating elements. These signals are transferred to the recombining circuits where the signals from all the elements are combined as they would be combined in space. The combination circuits provide two output signals, one which would appear on the centerline, and another which would appear at a small angular displacement from the centerline. This procedure is applied to both the course and clearance antennas producing four signals to be processed: course (on course), course (sensitivity), clearance (on course), and clearance (sensitivity).

Each of the recombined signals is sent to a peak detector which provides input to a pair of monitor channels. Two monitor channels are used for each signal to enhance the system reliability. All monitor channels compute DDM, SDM, and RF power level of the input signal and then check these values against specified tolerances for the signal being processed. If any of the computed parameters is out-of-tolerance, an alarm signal is sent to the control unit.

The far field monitoring (FFM) system is located on the extended runway centerline, typically between 3,000 and 4,000 feet from the approach end of the runway. It consists of an antenna and circuitry to detect and relay an alarm

condition. The signal detected by the antenna is divided and sent to two receivers, each of which provide output to a monitor channel. Each monitor channel computes the DDM, SDM and RF levels and checks these levels against tolerance limits, as in the integral monitor system. An out-of-tolerance condition must persist for a predetermined delay period of 70 to 120 seconds before the FFM sends an alarm signal to the system central unit. The processing of the monitor channel outputs as well as the time delay circuitry is in the FFM combining circuits.

Although the FFM is designed to monitor DDM, SDM and RF, as currently operated only an out-of-tolerance DDM can cause a true alarm condition. The tolerance limits for the SDM test circuitry have been set so wide as to render the SDM monitoring ineffective. Further, one of the two FFM monitor channels is adjusted to accept a wide variation in RF levels. Therefore, the transmission of a signal with incorrect power level will result in a monitor mismatch from the FFM and not an alarm condition.

The system control unit processes the output from all integral monitoring system channels as well as the output of the FFM and a temperature alarm. If both monitor channels which process the same signal produce an alarm, a transfer is effected from the main to the standby transmitter. If the system is operating with the standby transmitter when the alarms are received, the system is shut down. If an alarm condition is received from the FFM, the system is shut down independent of which transmitter is operating. A temperature alarm also causes a system shut down, although it is possible to configure the control unit such that a temperature alarm only results in an "abnormal" indication. An alarm from one monitor channel within a pair results in a "monitor mismatch" condition, with no direct effect on the system operation.

3.2 GLIDESLOPE

3.2.1 GLIDESLOPE SYSTEM VARIATIONS

All glideslope systems provide vertical guidance by producing signals with a predominance of a 90 Hz modulation component above the descent path, and a

predominance of a 150 Hz component below. The straight line descent path is formed where the modulation components are equal in strength. Aircraft systems compute DDM to determine the aircraft elevation with respect to the descent path. The glideslope signal processing performed in an aircraft is essentially the same as the corresponding localizer signal processing.

The GRN-27 glideslope is manufactured in two versions, one frequency and two frequency. The one frequency version is so designated because only a course signal is radiated while course and clearance signals are both radiated in the two frequency system. The one frequency system can be configured to generate one of two course radiation patterns, and depending on the pattern selected, the installation is designated as a "null reference" or "sideband reference" system. The selection of glideslope system or configuration to be used at any given site is generally based on the degree of irregularity of the terrain in the aircraft approach area.

The block diagram and radiation patterns for the one frequency glideslope are shown in Figure 3-2. The null reference vertical radiation pattern is essentially the same as the localizer horizontal pattern. The C+SB signal has a maximum signal strength on the descent path while the SBO signal has a null on the path. The relative phasing of the signals is adjusted to produce a predominance of the 90 Hz modulation component above the descent path, and a predominance of the 150 Hz component below the descent path. The one frequency sideband reference system produces less low angle radiation to reduce interference caused by reflected radiation from low angle obstacles. In this system, the C+SB beam is broader and shifted up with respect to the null reference C&SB beam. This is accomplished by reducing the height of the lower antenna. Also, the SBO beam pattern of both configurations has a null on the descent path, although the lower SBO beam in the sideband reference system has its angle of maximum signal shifted up and has lower power than the corresponding null reference beam. This is accomplished by introducing an SBO signal to the lower antenna which is out of phase with the signal to the upper antenna, and by reducing the height of the upper antenna as well as the lower antenna.

The two frequency glideslope block diagram and radiation pattern in shown in Figure 3-3. This system differs from the one frequency system in that a clearance signal is radiated and three antennas are used. By using the middle and

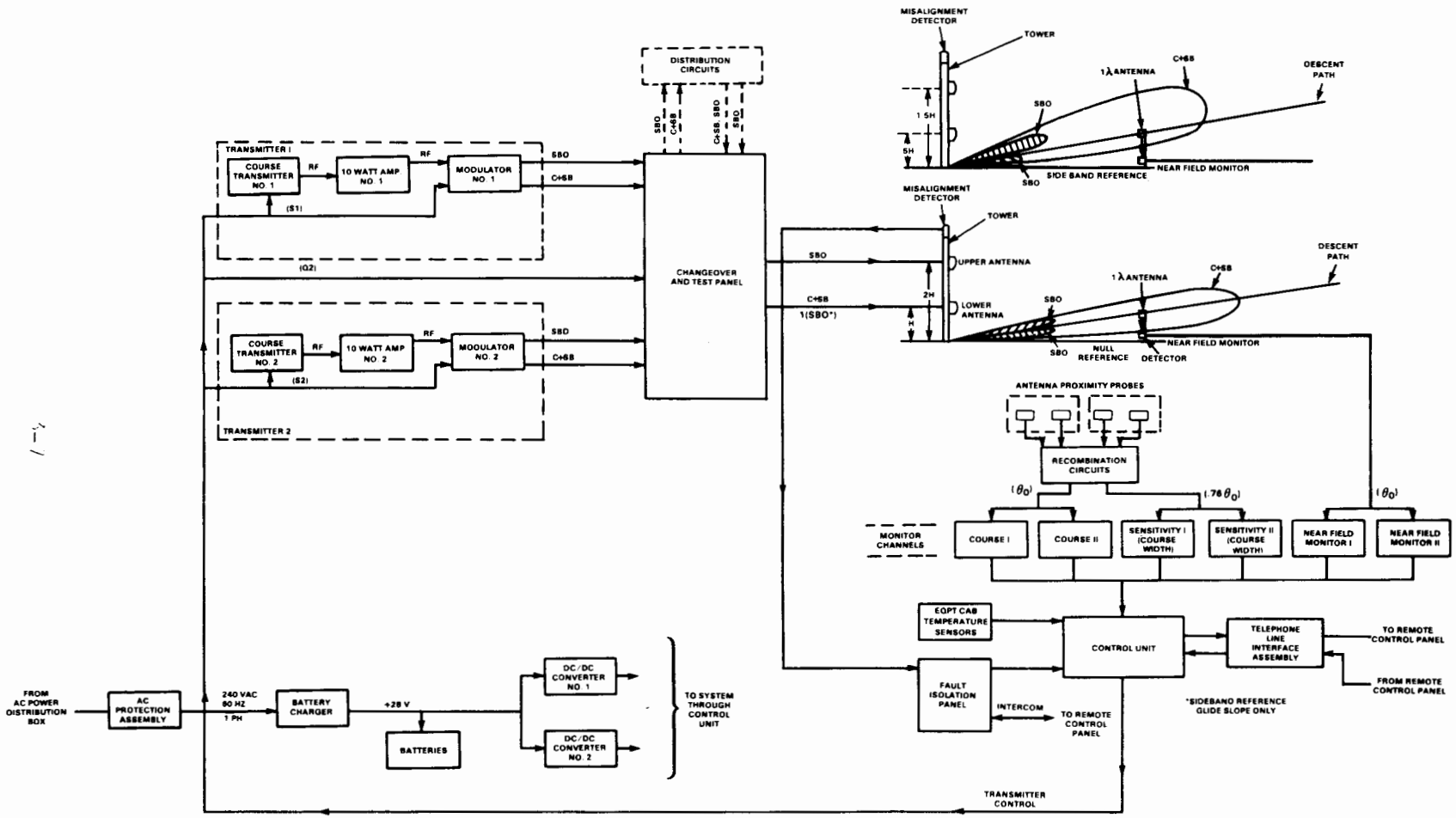


Figure 3.2. One Frequency Glide Slope Station, Functional Block Diagram.

lower antennas for the C&SB signal, the C&SB beam is made narrower with a maximum above the descent path. All three antennas are used for the SBO signal, making the lower SBO beam narrower and shifted further up than in the sideband reference system. Because of this reduction in course radiation at the lower angle, a clearance signal is radiated to provide fly up guidance below the course signal.

3.2.2 GLIDESLOPE FUNCTIONAL DESCRIPTION

Both glideslope systems are similar to the localizer in the use of a main and a standby transmitter, changeover and test panel, integral monitoring, recombination circuits, redundant monitor channels and a control unit. The glideslope systems utilize a near field monitor, however, as opposed to the far field monitor used with the localizer. A near field monitor alarm is delayed by two seconds before the glideslope is shut down. Other monitoring is essentially the same for the glideslope as for the localizer. The transfer and shutdown operation of the control unit is also essentially the same as that of the localizer control unit.

The one frequency glideslope transmitter systems do not include clearance transmitters, obviating the need for clearance monitoring equipment. In the null reference configuration, the SBO signal is channelled through the changeover and test panel to the upper antenna, while the C+SB signal is channelled to the lower antenna. In the sideband reference configuration, the distribution circuits are used to direct SBO to the upper antenna and SBO as well as C+SB to the lower antenna. The magnitude and phases of the SBO signals to the upper and lower antenna are set so that on the descent path the two signals cancel, producing an SBO null in the radiation pattern.

The two frequency glideslope transmitter system contains a clearance transmitter. All signals from the transmitter are sent to the antenna via the distribution circuits. In the distribution circuits phases and amplitudes are adjusted, after which signals are combined and sent to each antenna. The SBO signal from the middle antenna is zero on the descent path while the SBO signals from the upper and lower antenna cancel on the descent path, resulting in a total SBO null on the descent path.

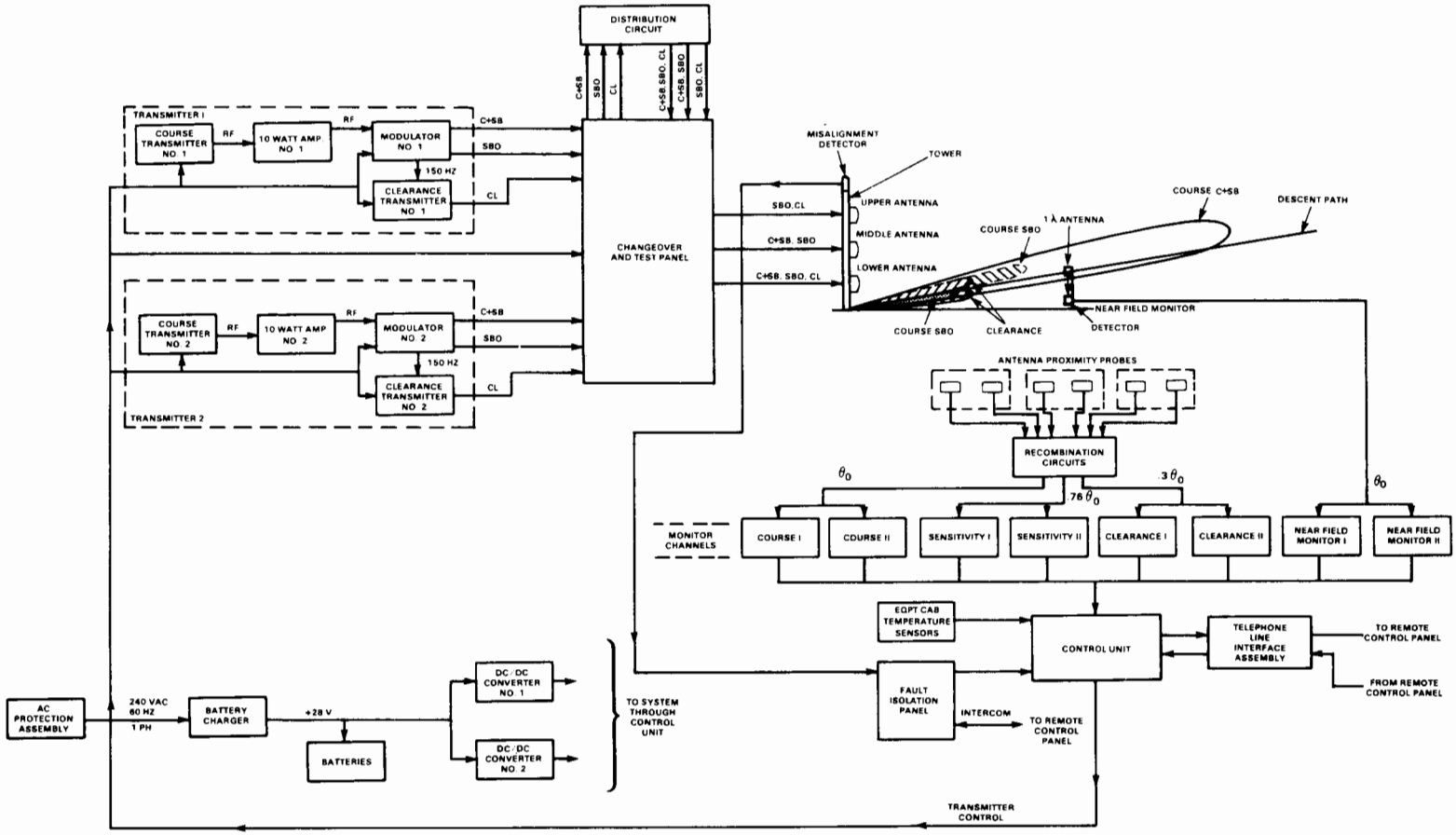


Figure 3.3. Two Frequency Glideslope Static Functional Block Diagram.

3.3 REMOTE CONTROL/MONITOR PANEL

The remote control/monitor panel receives and displays status information from the localizer and glideslope and allows remote control of transmitter selection. A separate control-indicator module is used for each localizer and each glideslope system installed. Each control-indicator module has the following four indicator lamps:

Main	-	indicates that the main transmitter is operating
Standby	-	indicates that the standby transmitter is operating
Off	-	indicates system is off
Abnormal	-	indicates abnormal condition, for example, monitor mismatch.

In addition to the indicator lamps, there are the following two switches on the control-indicator module:

Cycle	-	momemtary contact switch which causes the transmitters to cycle one step in a main-off-standby-off-main-etc. sequence each time the cycle switch is actuated.
Silence	-	silences an alarm buzzer which sounds when an abnormal condition or intercom call is initiated.

4.0 FAILURE ANALYSIS

4.1 SPECIFIC OBJECTIVES

This analysis provides the calculation of three types of failures of the radiated ILS signal:

1. Faulty Signal - a radiated signal which is out-of-tolerance with respect to one or more of its monitored parameters, except for the identification component.

2. Hazardous Signal - a signal which is out-of-tolerance with respect to on-course DDM and/or sensitivity, thus resulting in a potentially hazardous situation.

3. Total loss of signal, or shutdown of the localizer and/or glideslope station(s).

In the computation of a faulty signal, it would be desirable to compute the probability that any given parameter will exceed the tolerance limits set within the monitor channels for that parameter. However, it is virtually impossible to compute such a probability since it would be necessary to know the probability of every failure mode or degree of failure for each electronic component in the system. Such data is not available. Further, even if the data were available, the consideration of all piecepart failure modes would be far beyond the scope of this effort. Therefore, it has been assumed that any piece-part failure or combination of failures which could significantly degrade the radiated signal would, upon failure, produce an out-of-tolerance condition. The results presented in Reference 3 on the Mark III System imply that the same fundamental procedure was used in that study.

The basic ILS signal parameters which are monitored to ensure signal integrity are the following:

- on-course DDM
- on-course SDM
- on-course RF power
- course width (sensitivity)
- clearance DDM (localizer and two frequency glideslope only)

A signal for which any one of these parameters exceeds its tolerance is considered faulty. However, only signals with an incorrect on course DDM and/or course width would create a potentially hazardous situation. An incorrect on-course DDM could be the result of a shift of the centerline or the complete loss of the centerline. An incorrect course width would be the result of a signal producing zero, or very small, DDM everywhere. These failures must be considered hazardous.

The guidance provided by an ILS is not very sensitive to moderate changes in on-course SDM. In addition, the width monitor will indirectly monitor and prevent excessive SDM changes. Also, if the SDM level falls below an acceptable minimum, a flag appears in airborne ILS receivers indicating that the signal should not be used. Similarly, airborne receivers monitor RF power level, displaying a flag when the signal is not usable. Therefore, these parameters are not considered critical. With regard to the clearance signal, it is assumed that the critical portion of the landing sequence occurs in the final stages before touchdown during which the aircraft would be within the course signal. It is therefore assumed that a faulty clearance signal is not hazardous.

4.2 GENERAL APPROACH

All failure calculations were first performed for the GRN-27 as it is currently configured and operated. A number of possible changes in critical operating procedures and equipment were then considered to determine the most cost-effective method of improving the system reliability.

The reliability analysis in this study is based on the procedure used in the Mark III FMECA (Reference 3), modified to reflect the difference between the

Mark III and GRN-27 equipment and operating procedure. Briefly, all possible subsystem failure modes having a direct effect on the system operational status are determined from a functional block diagram of the system. The failure rate for each failure mode is then computed from the total failure rate of all piece-part components contributing to that mode within the specific subsystem. The various system failure probabilities are computed using equations which reflect the combinations and sequences of events which must occur to generate the corresponding failure effects. All events and combinations of events which contribute significantly to the radiation of a faulty signal or station shutdown are included in the equations. Many failure modes involving multiple independent failures were not included in the computation since their probability of occurrence could be estimated to be negligible.

In this study, the failure modes and rates given in Reference 3 were used unless differences between the GRN-27 and Mark III systems necessitated modifications, or unless an oversight or need for refinement of procedures was discovered in the Mark III study. The significant changes made are explained in the following section.

In the Mark III study, part failure rates were derived using RADC Reliability Notebook, Volume II (Reference 5). For the subassemblies with failure rates requiring revision for this study, failure modes were determined and failure rates calculated following the methodology of the Mark III FMECA. Part failure rates were derived using MIL-HDBK-217C, Military Standardization Handbook, Reliability Predictions of Electronic Equipment (Reference 4). Assumptions made for the part failure rate analysis are the same as those used in the Mark III study:

1. Equipment ambient temperature is 25° C.
2. Environment is "ground fixed"

4.3 MODIFICATIONS OF THE FAILURE ANALYSIS MADE FOR THIS STUDY

4.3.1 RECOMPUTED FAILURE RATES

The only subassemblies for which component failure rates had to be completely redone due to differences between the GRN-27 and Mark III systems were the control unit and the far field monitor combining circuits. These subsystems are completely different for the two types of equipment, requiring recalculation of failure rates and reassessment and redefinition of failure modes, to reflect structural differences. Also, combination of DDM, SDM and RF alarms from a single monitor channel is done in the control unit in the Mark III system, but is done in the monitors in the GRN-27. The monitor failure rates have been revised to include the failure rate for the logic circuitry which does this combining.

As will be discussed in Section 5, the course width failure rate is the single determining factor in the hazardous signal probability. Therefore, it was analyzed in detail and recomputed completely.

The analysis revealed that only a faulty SBO signal could affect the course width while leaving the on-course signal unperturbed. This is the result of the fact that the SBO signal has zero amplitude on course for all systems (see Section 3). Therefore, any fault which could alter the SBO signal before it is mixed with the C&SB signal could affect the course width. Such faults could occur in the modulator and changeover and test circuits in all systems, and in the distribution circuits of the localizer. The failure rates for failures resulting in a faulty signal were computed and used to compute the probability of a faulty course width.

This, in effect, is a refinement of the procedure in the Mark III FMECA, where the failure rate given for transmission of a faulty course width includes failures that would affect the on-course signal, and would, therefore, be detected by monitors other than the course width monitors.

4.3.2 REFORMULATED PROBABILITY EQUATIONS

The differences between the Mark III and GRN-27 systems which contribute most to the difference in reliability are the levels of redundancy in the monitoring and control systems. The probability equations for the Mark III system in Reference 3 were reformulated to reflect these differences, as itemized below:

1. There is no redundancy in the GRN-27 control unit. This is the single most important difference in the reliability between the GRN-27 and the Mark III system. Squared terms in the equations for the Mark III system are replaced throughout by linear terms, with a corresponding large increase in failure probability.

2. The GRN-27 has two monitor channels for each monitored parameter versus three in the Mark III system. The integral monitor factor in the probability equations is no longer squared, but becomes linear, only if landings are allowed with a monitor mismatch condition.

3. The GRN-27 has only one peak detector for each pair of integral monitor channels, whereas each monitor channel has a corresponding peak detector in the Mark III system. This difference is only critical with respect to shutdown probabilities, since the probability that a peak detector will fail in such a way as to simulate a signal that is in tolerance with respect to all parameters is negligible.

4. In the Mark III system, the standby transmitter is on, with its signal monitored and fed into dummy loads. The standby transmitter is off in the GRN-27, and therefore cannot be monitored. This increases the probability of hidden failure in the standby transmitter by removing the factors representing the standby monitoring from the Mark III equations.

5. The far field monitor has three monitor channels in the Mark III system, versus two in the GRN-27. The equations were revised to reflect this. This difference is not highly critical to the total probability of a faulty or hazardous signal, since far field monitoring appears in the

equations as an additional redundancy to the integral monitoring, making the term in which it occurs, the course DDM term, much smaller than the terms representing parameters not monitored by the far field montior.

6. The GRN-27 has no near field monitoring of the localizer signal. The equations were revised to reflect this, but for reasons similar to those discussed above for the far field monitor, this has no great effect on the total probability.

7. The glideslope antenna tower misalignment detector alarm does not cause a shutdown in the GRN-27, but only causes the "abnormal" indicator to light on the remote control panel. The probability equations were modified accordingly.

8. In the GRN-27 the near field monitor of the glideslope does not send an alarm, but only an abnormal indication, if RF power is out of tolerance. This factor was added to the corresponding Mark III equation.

9. A failure in the DC/DC converters causes an alarm in Mark III but not in the GRN-27. Therefore, a converter failure could remain undetected in the GRN-27 until a maintenance check of the power supply. Limited testing of the GRN-27 power supply is performed every month, and it is assumed that a converter failure would be detected during this testing. The maximum duration of an undetected converter failure is approximately 720 hours. This value was used in the computation of the GRN-27 power supply failure probability. This revision results in only a negligible increase in the total shutdown probability.

10. A localizer antenna misalignment detector (MAD) is used with the GRN-27 and not with the Mark III. This detector is designed to shut the system down upon detection of an antenna misalignment. The MAD unit has only a negligible effect on the course signal integrity, however, it does affect the shutdown probability. Shutdown can result from a MAD system failure or from the detection of an antenna misalignment. Since data was unavailable on the mercury switches used in the MAD systems, it was not possible to compute the effect of a MAD failure on the shutdown

probability. Also, since the probability of an antenna misalignment is unknown, its effect on the shutdown probability was not computed.

11. The generation of an erroneous signal inhibiting the monitors does not lead to shutdown in the GRN-27, as it does in the Mark III system. The corresponding terms were therefore deleted from the total shutdown probability.

Other differences between the GRN-27 and Mark III System were examined during the failure analysis and found to make no contribution to the failure calculations. These include a redundant battery charger in the Mark III system, three far field monitor antenna/receiver systems in the Mark III system vs. one in the GRN-27, and DDM alarms for both Category II and Category III tolerance in the Mark III.

Other changes in the Mark III system probability equations were required to correct errors in the methodology used for that system. These changes are described below:

1. In order for a faulty or hazardous signal to be undetected, all monitoring of the affected parameter(s) must fail before the corresponding failure in the transmitter occurs. To reflect this, a conditional probability factor must be added to the relevant probability equation. Taking this factor into account generally has the effect of increasing the calculated reliability by several orders of magnitude. The addition of these conditional factors is the single most important difference in methodology between this study and the Mark III FMECA.

2. According to our analysis, it is highly improbable that a faulty on-course SDM signal could be radiated without causing an alarm from the sensitivity monitors. Therefore, the failure rate for the sensitivity monitors has been added to the monitoring factor in the equation for the probability of an undetected faulty SDM signal.

3. In the Mark III FMECA, there are no terms in the relevant equations expressing the probability of a failure of the control unit to process a far field monitor alarm. Such a term has been added to the relevant equations in this study.

4. In the shutdown probability equations, the factor representing failures in the main transmitter causing a transfer has been replaced by a factor representing both failures in the main transmitter causing a transfer and failures in the control unit capable of causing a spontaneous transfer.

5. The localizer far field monitor and glideslope antenna misalignment detector alarms are delayed 70 and 135 seconds, respectively. During these intervals, the localizer DDM signal could be out of tolerance at the far field, or the glideslope signal could be faulty due to antenna misalignment, without being detected in either case. Terms expressing these probabilities have been added to the relevant equations.

4.4 VARIABLE FACTORS AFFECTING SYSTEM RELIABILITY BEHAVIOUR

4.4.1 EFFECTS OF OPERATING PROCEDURES AND EQUIPMENT CHANGES

A monitor mismatch on any pair of integral monitor channels is equivalent to a loss of redundancy in the monitoring. For example, if there is a monitor mismatch from the course monitor channels, a single hidden failure in the remaining course monitor would result in the undetected loss of integral monitoring of all on-course parameters. Since there is a significant difference in reliability between an operating procedure allowing landings with a monitor mismatch condition present and an operating procedure requiring matching non-alarm signals from all pairs of monitor channels, we have calculated the failure probabilities for both cases. Thus the number of matching monitors appears as a variable in the probability equations. For the GRN-27, the only indication of a monitor mismatch on the remote control panel is the lighting of the "abnormal" indicator light. Therefore, the reliability of an ILS for a particular category of operation could be enhanced if the system were down-

graded from that category when the remote abnormal light is on. Other faults which would also cause an abnormal indication (and no other indication) include:

- Primary AC power failure
- Battery charger failure
- Equipment cabinet temperature out of limits (optional)
- Glideslope misalignment detector alarm
- Localizer far field abnormal condition

Introducing a faulty signal into the various monitors and observing the proper system response verifies the integrity of the monitor and control unit alarm processing. Since this is a part of the periodic maintenance routine, the maintenance interval between such checks is a determining factor in the probability of a faulty or hazardous signal being undetected. This is reflected in the probability equations in Table C-1 and D-1. Current operating requirements for the GRN-27 specify a check of the monitors and control unit once every week. Therefore, a 168 hour maintenance interval was used to calculate the probabilities in the base case. The probabilities of faulty and hazardous radiation were also calculated for other maintenance intervals (see Section 5. 4). Hazardous signal probability as a function of maintenance interval was calculated (Figure 5.1) and analyzed to determine the frequency of maintenance checks necessary to achieve the proposed hazardous signal probability limits of 0.5×10^{-9} for localizer and glideslope, respectively.

The possibility of installing an automatic test circuit that would be capable of simulating faulty signals into the sensitivity monitors was investigated. This test circuit is discussed in Section 7.

Calculations were also performed to determine the effect of a system which would provide a remote indication of a far field monitor alarm during the 70 second delay period.

With this system in place, the corresponding far field monitor delay terms can be dropped from the probability equations; which, however, result in only a negligible increase in equipment reliability.

4.4.2 CRITICAL LANDING TIME

The probability of system shutdown within a specified landing time is a function of the time interval chosen. Based upon the consideration given in Section 2, shutdown probabilities were calculated for various critical landing times (Table 5.2). For the purpose of calculating a base case in Tables C-2 and D-2, critical intervals of 30 seconds and 15 seconds were used for the localizer and glideslope, respectively. This means that the base case presented is also the "worst case", with respect to shutdown probabilities, among the various critical intervals of interest.

4.4.3 ARBITRARY FACTORS

Two terms in the probability calculations involve probabilities that cannot be calculated in terms of equipment failure. These probabilities are: 1) the probability that the ILS signal will be faulty with respect to DDM tolerance at the far field only due to external runway disturbances during the critical phase of a landing, and 2) the probability that the glideslope antenna tower will become misaligned within the preventive maintenance interval. To avoid introducing extraneous assumptions into the result, we have set both these factors to zero in the base case. Assessment of the impact of these factors is made in Section 5.3.4.

5.0 RESULTS

5.1 FAILURE MODES, RATES AND EQUATIONS

All of the failure modes, failure rates and probability equations relevant to this study are contained in Appendices A through D. The data in these appendices have been used to compute the results contained in this section, and could be used to compute failure probabilities for other operating conditions or equipment configurations.

Appendices A and B contain subassembly (e.g. transmitter, control unit, etc.) failure modes and rates for the localizer and glideslope respectively. The first entry in the tables is the name of the subassembly and an identifying number. The ID number is used as the first subscript on a set of variables (lambdas) which are used to represent the failure rates in failure probability equations. A brief description of the function performed by each listed subassembly is contained in the third column.

The fourth, fifth and sixth columns contain the failure modes, the effect of each failure mode on the system and rate of failure for each mode. Each failure mode represents piecepart failures which could cause or contribute to that mode. The failure rates presented in column six represent a worst case since total piecepart failure rates are used even though a piecepart may have failure modes which do not contribute to the subassembly failure mode considered.

The failure modes within a subassembly are identified by a letter. In many cases, failure modes will small differences between them are categorized under one failure mode. These variations within a failure mode are identified by a number appended to the letter designating the overall mode. The letter or letter and number combination are used as subscripts, following the subassembly ID subscript, to identify the particular failure rate.

As indicated previously, most of the modes and rates used for this study are the same as those used in the Mark III FMECA. Failure rates in Appendices A and B which are different from the corresponding rates in the Mark III FMECA

are identified by an asterisk on the failure rate variable. Failure rates for failure modes which were not included in the Mark III FMECA are identified by a double asterisk. Many failure modes listed in the Mark III FMECA are not included in this analysis either because the mode does not exist in the GRN-27, or, to affect the signal, the mode must occur concurrently with two or more other modes, such occurrence being improbable.

Appendices C and D contain the faulty signal and shutdown probability calculations for the localizer and glideslope, respectively. For each type of faulty signal considered, an equation is presented representing the failure modes, combinations of failure modes, and sequences of failure modes which must occur to produce that faulty signal. The values of the variables in the probability equations are presented and used in two example calculations. One calculation is shown assuming landings would not be allowed after a monitor mismatch. Also, a one week maintenance interval has been assumed in all example calculations.

The shutdown probability calculations are shown in Tables C-2 and D-2 for the localizer and glideslope respectively. These results apply to a system which is operating on the main transmitter at the beginning of the critical landing period. The shutdown calculations are separated into single failures resulting in shutdown, and various categories of failure combinations, including a failure causing a transfer to standby, then a failure causing shutdown. As was done for the faulty signal probabilities, shutdown probability equations are presented along with the value of all variables in each equation. Example calculations were also shown, using a critical time of thirty seconds for the localizer and 15 seconds for the glideslope.

5.2 SUMMARY OF RESULTS

Table 5.1 contains a summary of the results of the reliability analysis, giving the reliability of the GRN-27 for various combinations of operating procedures and critical landing intervals. The headings divide the body of the table into four columns, each of which corresponds to the set of operating procedures specified by the headings above it. Assumptions regarding critical landing times affect shutdown probabilities only and, therefore, are shown in the shutdown section of the table.

ILS USE ALLOWED WITH ABNORMAL INDICATION		YES		NO	
INTERVAL BETWEEN SYSTEM CHECKS		1 WEEK	24 HOURS	1 WEEK	24 HOURS
Probability of the radiation of a faulty signal between system checks	Localizer	3.31×10^{-6}	6.75×10^{-8}	1.17×10^{-7}	2.37×10^{-9}
	Glideslope Two Frequency	2.33×10^{-6}	4.75×10^{-8}	7.79×10^{-8}	1.58×10^{-9}
	Null Reference	1.36×10^{-6}	2.78×10^{-8}	4.17×10^{-8}	8.42×10^{-10}
	Side Band Reference	1.47×10^{-6}	3.01×10^{-8}	4.31×10^{-8}	8.71×10^{-10}
Probability of the radiation of a hazardous signal between system checks	Localizer	8.75×10^{-8}	1.79×10^{-9}	1.53×10^{-8}	3.13×10^{-10}
	Glideslope Two Frequency	8.68×10^{-8}	1.77×10^{-9}	1.52×10^{-8}	3.11×10^{-10}
	Null Reference	8.75×10^{-8}	1.79×10^{-9}	1.53×10^{-8}	3.13×10^{-10}
	Side Band Reference	8.68×10^{-8}	1.77×10^{-9}	1.52×10^{-8}	3.11×10^{-10}
Probability of shutdown during critical landing interval specified	Localizer 30 sec.	1.81×10^{-7}	1.73×10^{-7}	1.80×10^{-7}	1.73×10^{-7}
	Localizer 15 sec.	9.07×10^{-8}	8.66×10^{-8}	9.01×10^{-8}	8.65×10^{-8}
	Localizer 10 sec.	6.05×10^{-8}	5.77×10^{-8}	6.01×10^{-8}	5.77×10^{-8}
	Glideslope Two Frequency 15 sec.	6.54×10^{-8}	6.43×10^{-8}	6.50×10^{-8}	6.42×10^{-8}
	Glideslope Two Frequency 5 sec.	2.18×10^{-8}	2.14×10^{-8}	2.17×10^{-8}	2.14×10^{-8}
	Null Reference 15 sec.	6.01×10^{-8}	5.91×10^{-8}	5.98×10^{-8}	5.91×10^{-8}
	Null Reference 5 sec.	2.00×10^{-8}	1.97×10^{-8}	1.99×10^{-8}	1.97×10^{-8}
	Side Band Ref. 15 sec.	6.27×10^{-8}	6.17×10^{-8}	6.24×10^{-8}	6.17×10^{-8}
	Side Band Ref. 5 sec.	2.09×10^{-8}	2.06×10^{-8}	2.08×10^{-8}	2.06×10^{-8}

Table 5.1 System Integrity and Continuity

The probabilities shown in Table 5.1 do not take into consideration external runway disturbances which can degrade the radiated signal. Also, the possibility of antenna support misalignment for either the localizer or glideslope are not included in the tabulated results. The faulty signal and shutdown probability equations in Appendices C and D contain terms which include the probabilities of runway disturbances or misalignment. However, since these probabilities are unknown, the results in Table 5.2 were computed assuming these probabilities to be zero.

The faulty signal probabilities shown are worst case values. Each is the sum of probabilities of different types of faulty signal (e.g. faulty DDM, SDM, RF, etc.) and the failure rates for certain control unit, monitor and transmitter failure modes are included in more than one term contributing to the total.

The shutdown probability is primarily determined by the probability of single part failures causing shutdown during the critical time interval. Therefore, the shutdown probability is essentially directly proportional to the critical time, as can be verified from Table 5.1.

Results are presented for critical time intervals of 30, 15 and 10 seconds for the localizer, and 15 and 5 seconds for the glideslope. The 30 and 15 second results can be used to determine whether the proposed ICAO reliability standards can be met, while the 10 and 5 second results can be used to compare against the results of previous analyses, such as the Mark III FMECA.

All the results in Table 5.1 assume the system is operating on the main transmitter before a landing attempt is allowed. If either the localizer or glideslope is operating with the standby transmitter, single transmitter component failures could cause a shutdown of the station. For the localizer, the total failure rate for single failures in the transmitter that would cause a shutdown when operating on standby is 83.11×10^{-6}. The corresponding figure for the glideslope is 36.01×10^{-6}. Adding these to the respective totals for single failures causing shutdown (pages C-16 and D-16), and re-

moving the probabilities for failure modes that cannot occur when operating on standby, gives the following probabilities of shutdown:

Localizer (30 second interval)	8.65×10^{-7}
Glideslope (15 second interval)	2.07×10^{-7}

As noted with respect to Table 5.1, shutdown probabilities are essentially independent of maintenance interval and whether operation is allowed with a monitor mismatch.

Hazardous signal probability is the same whether operation is with the main or standby transmitter.

5.3 SAMPLE DETAILED RESULTS

Each faulty signal probability listed in Table 5.1 is the sum of the probabilities of a number of different types of faulty signal (DDM, SDM, etc.). Similarly, the shutdown probabilities are the sum of the probabilities of a number of different shutdown modes. To show how the results in Table 5.1 were obtained, it is useful to list detailed failure probabilities for a few of the cases in the table. The cases selected involve the localizer and two frequency glideslope, a one-week interval between system checks, and 30 and 15 second critical landing intervals for the localizer and glideslope respectively. Separate results are presented assuming landings are allowed with a monitor mismatch and assuming landings are not allowed with a mismatch. These are the cases for which calculations were performed in Appendices C and D.

Table 5.2 contains the detailed results assuming landings would be allowed with a monitor mismatch (referred to as the base case in the Appendices). This corresponds to the current configuration and operation of the system. The precise definition of each of the probabilities is contained in Appendices C and D.

Table 5.2 Base Case Failure Probability

A. Localizer Faulty Signal Probability

1.	$P_{CSE_{DDM}}$:	2.023×10^{-12}
2.	$P_{CSE_{SDM}}$:	9.918×10^{-7}
3.	$P_{CSE_{RF}}$:	1.095×10^{-6}
4.	P_{SEN} :	8.753×10^{-8}
5.	P_{CL} :	1.133×10^{-6}
6.	P_{FF} :	0
		3.308×10^{-6}

B. Glideslope Faulty Signal Probability

1.	$P_{CSE_{DDM}}$:	9.001×10^{-13}
2.	$P_{CSE_{SDM}}$:	7.548×10^{-7}
3.	$P_{CSE_{RF}}$:	7.331×10^{-7}
4.	P_{SEN} :	8.676×10^{-8}
5.	P_{CL} :	7.522×10^{-7}
6.	P_{ATM} :	0
		2.326×10^{-6}

Table 5.2 Base Case Failure Probability (continued)

C. Localizer Shutdown Probability

1.	P_S	:	1.711×10^{-7}
2.	P_{AB}	:	4.988×10^{-13}
3.	P_{AC}	:	8.461×10^{-12}
4.	$P_{STBY_{CSE}}$	:	1.305×10^{-9}
5.	$P_{STBY_{SEN}}$	:	2.536×10^{-10}
6.	$P_{STBY_{CL}}$	:	6.391×10^{-10}
7.	$P_{STBY_{ID}}$	:	1.136×10^{-9}
8.	P_{STBY}	:	5.071×10^{-9}
9.	P_{CONV}	:	5.920×10^{-10}
10.	$P_{CSE/ID}$	:	3.341×10^{-10}
11.	P_{SEN}	:	1.289×10^{-10}
12.	P_{CL}	:	2.947×10^{-10}
13.	P_{FF}	:	4.536×10^{-10}
			1.813×10^{-7}

Table 5.2 Base Case Failure Probability (continued)

D. Glideslope Shutdown Probability

1.	P_S	:	6.395×10^{-8}
2.	P_{AB}	:	2.453×10^{-14}
3.	P_{AC}	:	4.075×10^{-12}
4.	$P_{STBY_{CSE}}$	:	2.167×10^{-10}
5.	$P_{STBY_{SEN}}$	:	1.082×10^{-10}
6.	$P_{STBY_{CL}}$	:	5.399×10^{-11}
7.	P_{STBY}	:	4.983×10^{-10}
8.	P_{CONV}	:	1.306×10^{-10}
9.	P_{CSE}	:	1.168×10^{-10}
10.	P_{SEN}	:	6.445×10^{-11}
11.	P_{CL}	:	1.233×10^{-10}
12.	P_{NF}	:	1.052×10^{-10}
			6.538×10^{-8}

Table 5.2 Base Case Failure Probability (continued)

E. Summary

Faulty Signal Probability

Localizer	3.308×10^{-6}
Glideslope	2.326×10^{-6}

Shutdown Probability

Localizer	1.813×10^{-7}
Glideslope	6.538×10^{-8}

For both the localizer and glideslope, the on-course DDM fault probability is several orders of magnitude smaller than the other non-zero terms. This is the result of the added redundancy in the monitoring represented by the far-field monitor and its independent processing in the control unit.

Although the hazardous signal probabilities are not specifically listed in Table 5.2, they are the same as the probabilities of a signal with faulty sensitivity. A hazardous signal can result from a faulty on-course DDM or a faulty sensitivity, and, since the on-course DDM fault probability is so small, the sum of these two terms is equal to the faulty sensitivity probability.

From Table 5.2, Sections C and D, it can be seen that the shutdown probabilities are dominated by the probability of a single failure causing a shutdown (F_S). This is to be expected since the probability of multiple failures is the product of the individual probabilities, generally resulting in a low value.

Table 5.3 contains detailed results for the same case with the exception that it is assumed that the landings would not be allowed with a monitor mismatch. Since the remote control panel indication of a monitor mismatch is the lighting of an "abnormal" indicator, the reliability values shown in Table 5.3 can be achieved if ILS use is not allowed when there is an "abnormal" indication.

Table 5.3 can be compared with Table 5.2 to show the improvement in reliability over the base case made by not allowing landings with a monitor mismatch condition. A comparison of the tables indicate that the faulty signal probabilities are significantly reduced by preventing landings during a monitor mismatch. However, the shutdown probabilities are not significantly affected.

Table 5.3 Base Case Probabilities With Landings Not Allowed with a Monitor Mismatch

A. Localizer Faulty Signal Probability

1.	$P_{CSE_{DDM}}$:	4.667×10^{-16}
2.	$P_{CSE_{SDM}}$:	3.082×10^{-8}
3.	$P_{CSE_{RF}}$:	3.553×10^{-8}
4.	P_{SEN} :	1.534×10^{-8}
5.	P_{CL} :	3.551×10^{-8}
6.	P_{FF} :	0
		1.172×10^{-7}

B. Glideslope Faulty Signal Probability

1.	$P_{CSE_{DDM}}$:	1.370×10^{-15}
2.	$P_{CSE_{SDM}}$:	2.899×10^{-8}
3.	$P_{CSE_{RF}}$:	3.917×10^{-14}
4.	P_{SEN} :	1.525×10^{-8}
5.	P_{CL} :	3.363×10^{-8}
6.	P_{ATM} :	0
		7.788×10^{-8}

Table 5.3 Base Case Probabilities With Landings Not Allowed with a Monitor Mismatch (Continued)

C. Localizer Shutdown Probability

1.	P_S :	1.711×10^{-7}
2.	P_{AB} :	4.988×10^{-13}
3.	P_{AC} :	8.461×10^{-12}
4.	$P_{STBY_{CSE}}$:	1.305×10^{-9}
5.	$P_{STBY_{SEN}}$:	2.536×10^{-10}
6.	$P_{STBY_{CL}}$:	6.391×10^{-10}
7.	$P_{STBY_{ID}}$:	1.136×10^{-9}
8.	P_{STBY} :	5.071×10^{-9}
9.	P_{CONV}	5.920×10^{-10}
10.	$P_{CSE/ID}$:	1.657×10^{-14}
11.	P_{SEN} :	6.394×10^{-15}
12.	P_{CL} :	1.461×10^{-14}
13.	P_{FF} :	2.250×10^{-14}
		1.801×10^{-7}

Table 5.3 Base Case Probabilities With Landings Not Allowed with a Monitor Mismatch (Continued)

D. Glideslope Shutdown Probability

1.	P_S :	6.395×10^{-8}
2.	P_{AB} :	2.453×10^{-14}
3.	P_{AC} :	4.075×10^{-12}
4.	$P_{STBY_{CSE}}$:	2.167×10^{-10}
5.	$P_{STBY_{SEN}}$:	1.082×10^{-10}
6.	$P_{STBY_{CL}}$:	5.399×10^{-11}
7.	P_{STBY} :	4.983×10^{-10}
8.	P_{CONV} :	1.306×10^{-10}
9.	P_{CSE} :	2.897×10^{-15}
10.	P_{SEN} :	1.598×10^{-15}
11.	P_{CL} :	3.058×10^{-15}
12.	P_{NF} :	2.609×10^{-15}
		6.497×10^{-8}

Table 5.3 Base Case Probabilities With Landings Not Allowed with a Monitor Mismatch (Continued)

E. Summary

Faulty Signal Probability

Localizer	1.172×10^{-7}
Glideslope	7.788×10^{-8}

Shutdown Probability

Localizer	1.801×10^{-7}
Glideslope	6.497×10^{-8}

5.4 PREVENTIVE MAINTENANCE CYCLE

As discussed in Section 4.4.1, the probability of a faulty or hazardous signal is determined by the frequency of checks of the monitoring and transfer operation. Figure 5.1 gives the probability of an undetected hazardous signal as a function of the maintenance interval between such checks. Note that a probability of hazardous signal of 0.5×10^{-9} may be achieved by a maintenance interval of 30.3 hours if landings are not allowed with an "abnormal" indication (monitor mismatch), or by a maintenance interval of 12.7 hours if landings are allowed with an "abnormal" indication.

5.5 UNKNOWN FACTORS

5.5.1 FAR FIELD LOCALIZER SIGNAL DEGRADATION DUE TO RUNWAY DISTURBANCE

The probability of an undetected degradation of the course position signal at the far field only is a function of the probability of external runway disturbances. Since the degraded signal may be hazardous, it is desirable to evaluate its probability with respect to the proposed integrity level of 0.5×10^{-9}. Specifically, our analysis was directed toward discovering the values of the probability of external runway disturbances resulting in signal degradation for which the associated hazardous signal probability meets the proposed integrity level. Since the probability of hazardous signal due to external runway disturbances is only one component of the total hazardous signal probability, it was provisionally set equal to 0.1×10^{-9}. We then solved for the probability of external runway disturbances necessary to guarantee that value.

The probability that a faulty course position at the far field will be radiated during the 70 second delay of the far field monitor alarm is the dominant term in the calculation of the hazardous signal probability due to external runway disburbances. This term is zero if the far field monitor is monitored with no delay at the remote control panel. With remote control monitoring of the far field monitor, the values for the probability of external runway disturbances necessary for the desired signal integrity are as follows:

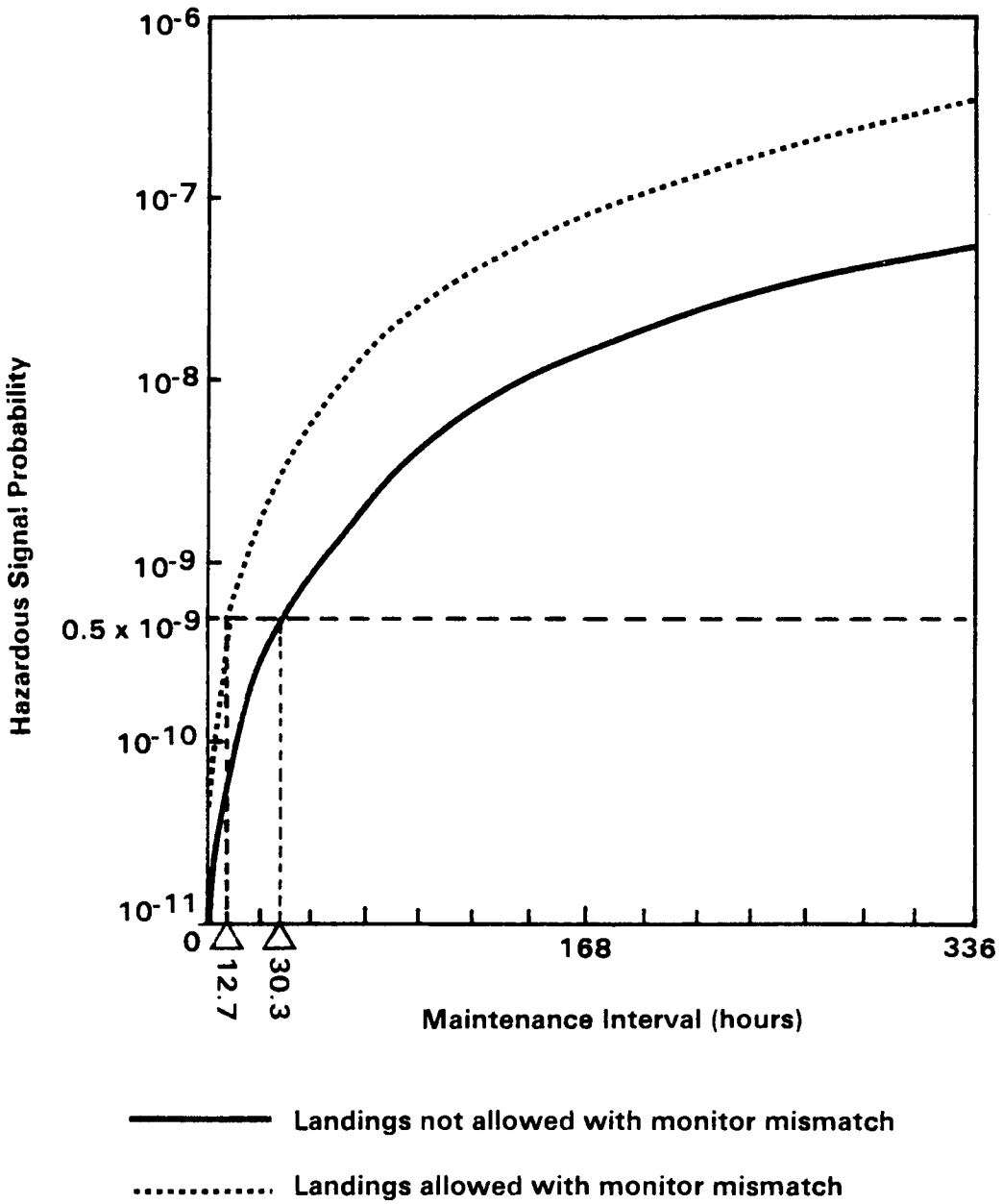


Figure 5.1. Localizer or Glideslope Signal Integrity as a Function of Preventive Maintenance Interval

If landings are allowed with "ABN" light on, a probability of external runway disturbances less than 8×10^{-8} gives a probability of hazardous signal at the far field of less than 0.1×10^{-9}. If landings are not allowed with "ABN" light on, the probability of hazardous signal at the far field is less than 3.1×10^{-13}, independent of the probability of external runway disturbances.

Without remote control monitoring, the probability of external runway disturbances must be less than 4.3×10^{-11} in order for the corresponding hazardous signal probability to be less than 0.1×10^{-9}.

The threshold values given are to be compared with estimates of the probability of signal degradation due to external runway disturbances derived from other sources; such as, for example, site-specific experience, in order to determine if the probability of the radiation of a faulty course position at the far field is within the proposed limits.

See Appendix C, Page C-15 for the equations used to calculate the probabilities discussed in this section.

5.5.2 GLIDESLOPE ANTENNA MISALIGNMENT DETECTOR

The misalignment detector detects a permanent tilt of the antenna tower and produces an abnormal indication, in effect providing a warning before a tilt is serious enough to cause a shutdown due to near field monitor action. Further, a tower misalignment could have effects on clearance and sensitivity undetected by the near field monitor. Since the degree of tilt detected by the misalignment detector would affect the glideslope path near the runway threshold if the tilt was towards or away from the runway, this provides an additional argument for downgrading the system when an abnormal indication at the remote control panel occurs. (In the Mark III System, a misalignment detector alarm causes shutdown).

The probability of the radiation of a faulty signal, due to antenna tower misalignment is a function of the probability that the glideslope antenna tower

will become misaligned (within the preventive maintenance interval), which is unpredictable, being a function of external and uncontrollable forces. Since the resulting signal may be hazardous, it is desirable to evaluate its probability with respect to the proposed integrity level of 0.5×10^{-9}. Specifically, our analysis was directed toward discovering the values of the probability of antenna misalignment for which the associated hazardous signal probability meets the proposed integrity level. Since the probability of hazardous signal due to antenna misalignment is only one component of the total hazardous signal probability, it was provisionally set equal to 0.1×10^{-9}. We then solved for the probability of antenna misalignment necessary to guarantee that value.

The probability that a hazardous signal due to antenna misalignment will be radiated within the 2.25 minute (135 second) delay of the antenna misalignment alarm is the dominant term in the calculation of the hazardous signal probability due to misalignment. This term is zero if the misalignment detector is monitored with no delay at the remote control panel (although this option is not under consideration).

Without remote control monitoring, the probability of tower misalignment must be less than 4.5×10^{-7} in order for the hazardous signal probability due to misalignment to be less than 0.1×10^{-9} (assuming a 168 hour maintenance interval). With remote control monitoring, and not allowing landings with an abnormal indication present, the tower misalignment probability must only be less than 1.8×10^{-7}. If landings are allowed with an abnormal indication, the tower misalignment probability must simply be less than 0.1×10^{-9} (essentially no monitoring).

The threshold values given are to be compared with estimates of tower misalignment probability derived from other sources; such as, for example, site-specific experience, in order to determine if the probability of a hazardous signal due to tower misalignment is within the proposed limits.

See Appendix D, Page D-15 for the equations used to calculate the probabilities discussed in this section.

5.6 REVISED MARK III RELIABILITY RESULTS

Table 5.4 provides the results from the FMECA of the Mark III System (Reference 3) and the same results modified to conform to the methodology used in this study, for purposes of comparison of the reliability of the Mark III and the GRN-27. The modifications are listed below:

- Conditional factors were added to the faulty and hazardous signal equations.

- Transmitter failure rates in the sensitivity terms were replaced by failure rates for transmission of faulty SBO only.

- Changes were made to reflect assumptions made for the GRN-27 base case:

  1. A maintenance interval of 168 hours was assumed, unless otherwise noted;

  2. critical landing times assumed were 30 seconds for localizer, 15 seconds for glideslope;

  3. arbitrary factors (localizer signal degradation due to external runway disturbances, glideslope antenna tower misalignment) were set to zero.

- Hazardous signal probability is the sum of the DDM and sensitivity terms only.

Table 5.4 Revised Mark III Reliability Results

	Results from Mark III FMECA (Reference 3)	Mark III Results Revised to Conform to Methodology of GRN-27 Study*
Faulty Signal Probability		
Localizer	9.334×10^{-9}	2.296×10^{-12}
Glideslope	9.089×10^{-9}	1.495×10^{-12}
Hazardous Signal Probability		
Localizer	2.141×10^{-10}	6.791×10^{-14}
Glideslope	1.518×10^{-10}	6.798×10^{-14}
Shutdown Probability		
Localizer	5.617×10^{-8}	1.655×10^{-7}
Glideslope	2.600×10^{-8}	7.706×10^{-8}

*Conditional factors added to faulty and hazardous signal equations; hazardous signal probability is sum of hazardous DDM and sensitivity terms given in Mark III study, with transmitter failure rate in sensitivity term replaced by failure rate for transmission of faulty SBO only; maintenance interval and critical landing times are same as for GRN-27 base case; arbitrary factors (runway disturbance, misalignment, antenna tower) set to zero.

6.0 FIELD EXPERIENCE

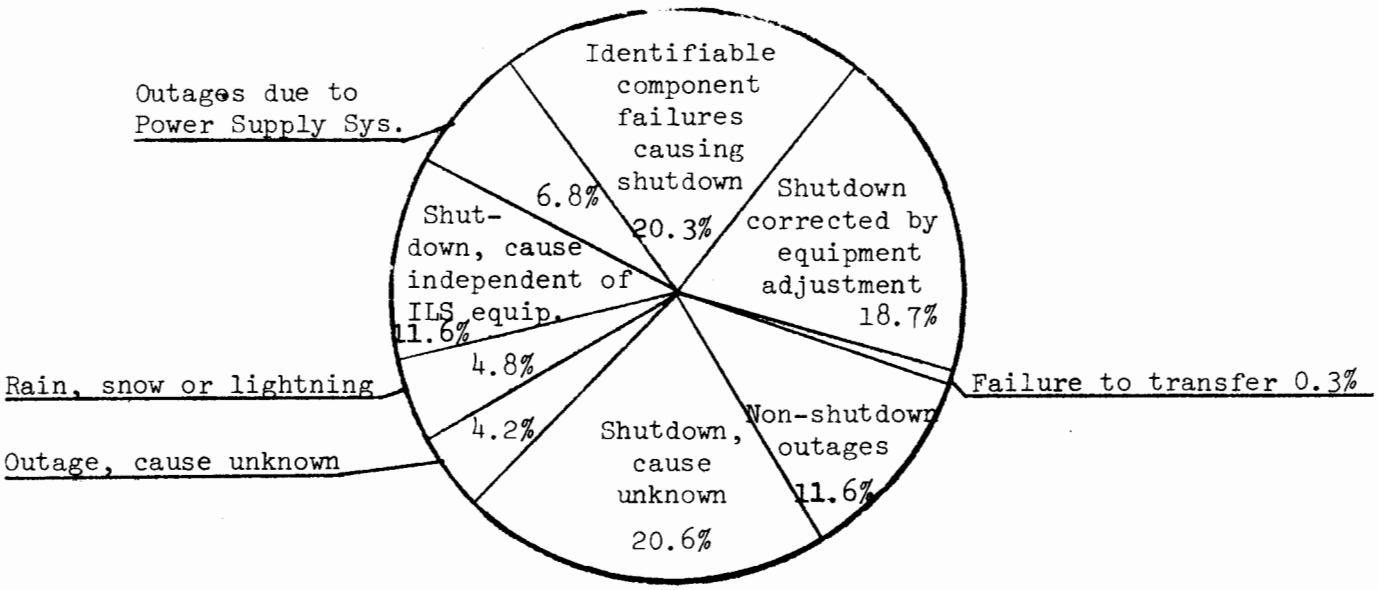
6.1 FACILITY MAINTENANCE LOGS

Table 6-1 summarizes GRN-27 unscheduled outages for the calendar year 1981, as recorded in the maintenance logs from 69 facilities. Causes of outages are seldom categorically stated in the logs, and most often must be deduced from the repair/maintenance acitvity recorded as the response to the outage. When the equipment repaired cannot have caused shutdown by itself (for example, one of the two transmitting units), the outage has been put in the same class as those for which the maintenance technicians explicitly noted "no cause found".

Figure 6-1 below is a graphic summary of all outages, derived from the facility maintenance logs.

Figure 6-1

GRN-27 Unscheduled Outages (1981)



Not all of the outages recorded were the result of automatic shutdowns, or failures which result in a loss of signal (such as power failures). Some outages represent failures to bring up the equipment when switching from one runway to another. Others represent instances of the system being taken out of service for repair, or to investigate an "abnormal" indication.

Outages involving repair actions on the transmitting units only were most likely either shutdowns of the standby transmitter, after operation for some period on standby, or a result of repair action taken to correct some irregularity or abnormal indication. In either case, there would have been an "abnormal" indication, or some other failure indication, for some period of time before shutdown, unless the standby transmitter was already faulty before a transfer occurred, causing a shutdown as soon as the main transmitter failed and transfer to standby was made. None of these cases could be distinguished from each other on the basis of the information in the logs, nor could it be determined with confidence that the transmitter subassembly repaired was the direct cause of the outage. Therefore, all such cases were included among outages with unknown causes.

6.2 COMPARISONS WITH THE FAILURE ANALYSIS

If all outages other than those determined to be non-shutdown outages (Class VIII in Table 6-1) are assumed to be shutdowns, we have the following actual worst case shutdown probabilities:

Localizer

Probability of shutdown in a 30 second interval: 2.15×10^{-6}

Probability of shutdown in a 15 second interval: 1.07×10^{-6}

Glideslope

Probability of shutdown in a 15 second interval: 8.75×10^{-7}

The probabilities are derived by dividing the respective number of outages for the localizer or glideslope by the number of 30 or 15 second intervals in the 585,940 total uptime hours for each type of facility in the maintenance logs analyzed.

More realistic probabilities result from counting only those outages for which repair or adjustment of identifiable components is recorded in the logs (I, II, III and VII in Table 6-1):

Localizer

Probability of shutdown in a 30 second interval: 8.68×10^{-7}

Probability of shutdown in a 15 second interval: 4.34×10^{-7}

Glideslope

Probability of shutdown in a 15 second interval: 5.90×10^{-7}

For purposes of comparison with the theoretical analysis, only identifiable failures that cannot be corrected by adjustment, but only by repairing or replacing the failed part (I and II in Table 6-1), should be included in the probability calculation. This procedure gives the following results:

Localizer

Probability of shutdown in a 30 second interval: 4.41×10^{-7}

Probability of shutdown in a 15 second interval: 2.20×10^{-7}

Glideslope

Probability of shutdown in a 15 second interval: 4.69×10^{-7}

For comparison, the corresponding theoretically calculated probabilities (from Table 5.1) are:

Localizer

Probability of shutdown in a 30 second interval: 1.81×10^{-7}

Probability of shutdown in a 15 second interval: 9.07×10^{-8}

Glideslope

Probability of shutdown in a 15 second interval: 6.54×10^{-8}

A 168 hour maintenance interval is assumed. Also, the calculated probability for the glideslope is for the two frequency glideslope (worst case).

Actual experience, as represented in the logs, identifies the peak detectors as causing outages with a relatively high frequency. The total calculated peak detector failure rate contributing to the probability of shutdown is 3.52×10^{-6}. But actual experience gives a much higher failure rate, with 36 failures in 1,206,280 system hours, or a failure rate of 2.98×10^{-5} failures per hour. This is a confirmation of a known problem area, for which proposed improvements have been discussed in Section 7.

The localizer misalignment detectors were involved in several outages other than those attributed to misalignment detector component failures. Two of the three outages due to corrosion were due to corroded wires on the tilt detectors. Also, both outages listed as due to rodent activity were the result of rats having gnawed the insulation off wires connected to the tilt detector. Further, only two of the outages listed under "Antenna Misalignment" were due to permanent antenna misalignment. Two were attributable to storm, and one to aircraft departures. (The outage listed under "earthquake" was also caused by MAD alarms.) And, finally, three outages listed under unknown causes were due to inexplicable MAD alarms, with no fault found in the antennas or detectors.

The actual reliability of the monitor alarm processing circuitry in the control unit is of interest in assessing the level of confidence in the theoretically calculated probability of a hazardous signal. No outage was explicitly blamed on a failure in the alarm processing circuitry, and only once in the 1,206,280 uptime hours was the alarm and transfer card in the control unit replaced (during troubleshooting) in connection with an unscheduled outage. This corresponds to a failure rate of 8.25×10^{-7}, which agrees well with calculated failure rates involving this subassembly. Although the monitors required more frequent repair, their contribution to the hazardous signal probability is effectively eliminated by not allowing landings with a monitor mismatch condition.

Table 6-1

GRN-27 Unscheduled Outages (1981)

Type of Outage	Number of Outages			Percentage of all outages
	Localizer	Glideslope	Total	
I. Component failures causing shutdown				
Peak Detector	15	21	36	11.6%
Recombining Circuits	4	3	7	2.3
Changeover and Test	4	2	6	1.9
Distribution Circuits	2	3	5	1.6
Misalignment Detector (does not include corrosion-related failures)	3	N/A	3	1.0
Far Field Monitor	2	N/A	2	0.6
Proximity Probe	0	1	1	0.3
Antenna Coupler	0	1	1	0.3
Monitor Interface	0	1	1	0.3
Connector on Monitor Feed Cable	0	1	1	0.3
All single component failures	31	33	64	20.6%
II. Shutdown resulting from faulty signal, followed by failure to effect changeover	1	0	1	0.3%
III. Shutdown, corrected by adjustment of the indicated subassembly				
Peak Detector	2	13	15	4.8%
Transmitters	6	9	15	4.8
Monitors	3	10	13	4.2
Loose Hardware	6	3	9	2.9
Near Field Monitor	N/A	2	2	0.6
Far Field Monitor	1	N/A	1	0.3
Distribution Circuits	1	0	1	0.3
Unknown	0	2	2	0.6
All shutdowns corrected by adjustment	19	39	58	18.7%

Table 6-1

GRN-27 Unscheduled Outages (1981) (Continued

Type of Outage	Number of Outages			Percentage of all Outages
	Localizer	Glideslope	Total	
IV. Shutdown due to snow, rain or lightning				
Snow	6	3	9	2.9%
Rain	2	1	3	1.0
Lightning	1	0	1	0.3
Unspecified weather-related outage	0	2	2	0.6
Subtotal	9	6	15	4.8%
V. Shutdown not caused by ILS equipment				
Commercial lines	14	2	16	5.2%
Antenna Misalignment (detected by misalignment detector)	5	0	5	1.6
Corrosion	3	0	3	1.0
Improper Operation	1	2	3	1.0
External Runway Activity	0	3	3	1.0
Faulty Shelter Heater or Air Conditioner	2	1	3	1.0
Rodent Activity	2	0	2	0.6
Earthquake	1	0	1	0.3
Subtotal	27	8	35	11.6%
VI. Shutdown, cause unknown	43	21	64	20.6%

Table 6-1

GRN-27 Unscheduled Outages (1981) (Continued)

Type of Outage	Number of Outages			Percentage of all Outages
	Localizer	Glideslope	Total	
VII. Outages due to power supply system				
Blown fuses or tripped circuit breakers	5	9	14	4.5%
Loss of prime power, with ensuing failure in back-up	5	2	7	2.3
Subtotal	10	11	21	6.8%
VIII. Non-shutdown outages				
System taken out for repair	12	6	18	5.8%
Failure to come up	15	3	18	5.8
Subtotal	27	9	36	11.6%
IX. Outage, unknown cause (unclear if outage was a shutdown)	11	2	13	4.2%
Total	178	132	310	

7.0 POSSIBLE EQUIPMENT MODIFICATIONS

7.1 TEST SWITCH

Each monitor channel in the GRN-27 contains a switch which can be used to test parts of the system. When thrown, the switch activates a relay, thereby introducing a faulty signal into the monitor channel. Activating the switches on any pair of channels, both of which monitor the same parameter, should result in a transfer from the main to the standby transmitter. A second activation of the switches should result in a system shutdown. Using these switches to test for a transfer of transmitters is a simple method of verifying that critical components in the control unit are operating. The test also verifies the operation of the monitor channels. However, because of monitor channel redundancy, failures in the control unit are far more like to produce a hazard.

To achieve the high levels of reliability required for Category III equipment, it would be necessary to test the GRN-27 more frequently than currently required. It would be sufficient to use the monitor channel switches to perform this test since possible hidden failures in the control unit are the primary cause of the relative unreliability of the system. One possible approach to performing these tests would be to install a switch in the control tower or tower equipment room which could be used to test the system remotely. After the remote switch is activated, the tester would observe on the remote indicator panel that a transfer from main to standby has taken place (indicator lights and aural alarm indicate the change of status). The system would then be restored using the cycle switch on the remote control panel.

One possible implementation of the remote test switch would minimize the attention required of the tester and minimize the duration of the signal interruption. This system would be semi-automatic in that an operator would simply press a momentary contact switch. The system would then automatically transmit a signal to the equipment shelter which activates the test circuitry for a precise interval. The interval would be longer than the delay time on the alarm and transfer circuit card (used to prevent transients from effecting a transfer),

but sufficiently short such that the transfer is not immediately followed by a shutdown. The semi-automatic system would, after a short delay, transmit a pulse which would activate the Monitors Locally Bypassed (MLB) signal in the control unit, thereby restoring the main transmitter. A cycle pulse could be used to restore the system but the cycle pulse would first shut the system off, after which the system would remain off for twenty seconds before the next cycle pulse could restore the system.

7.2 TOWER MONITORING OF THE FAR FIELD MONITOR

The far field monitor does not issue an alarm until a faulty signal has been received continuously for a delay interval of between 70 and 120 seconds. Therefore, it would be useful to provide the controller with some indication of a faulty signal at the far field monitor during the delay interval. A controller could discriminate between faulty signals caused by temporary obstructions, such as overflights or taxiway activity, and those with no apparent cause, such as a system fault. Such a remote display system has been built at the NAVAIDS/COMM Engineering Branch of the FAA Aeronautical Center, and is currently being tested. This type of display unit will have only a negligible effect on the probability of radiation of a faulty signal due to a system failure. However, it would reduce the probability that a landing would occur while the signal is distorted by an obstruction. The specific impact is impossible to determine without data on the probability and duration of all types of signals reflecting obstructions. Example calculations of the display unit impact are shown in Section 5.5.1.

7.3 IMPROVED TRANSMITTER

The GRN-27 transmitters were designed in the late 1960's at which time there was a limited quantity and quality of solid state RF devices. Also, D.C. to R.F. conversion efficiencies obtainable with these early devices were relatively low. Considering these constraints, the reliability and output power levels of the GRN-27 were respectable. However, significant improvements can be realized with the use of current technology solid state RF power devices.

Southwestern Communications, Inc. has designed and tested improved transmitter power amplifiers for both the localizer and glideslope systems. The improved amplifiers have been designed as plug-in replacements for the original equipment A4 circuit boards. The advantages of using the improved amplifier in the localizer are:

- Higher reliability - the computed failure rate for the improved circuit is 0.14 failures per million hours, compared to 1.38 for the original equipment.

- No frequency drift occurs in the improved circuit whereas the original equipment requires periodic readjustment after turn-on.

- Shorter time required for transmitter stabilization.

- The same power amplifier is used in the course and clearance transmitters. However, the lowest power level to which the original amplifier can be adjusted is often too high for the clearance transmitter, which must meet a 10 db course to clearance power ratio criterion. The improved circuit can be adjusted to sufficiently low levels to meet the criterion.

Similarly, the replacement amplifier circuit for the glideslope transmitter has the following advantages:

- Higher reliability - the computed failure rate for the improved circuit is 0.44 failures per million hours compared to 4.11 for the original equipment.

- The original equipment amplifier contains components which will soon become unavailable (2N5016 transistor).

- The improved circuit can produce 15 watts of power as opposed to 10 watts for the original equipment.

- Lower power levels are possible with the improved amplifier making it possible to meet the 10 db course to clearance power ratio criterion.

Although the new amplifiers would not have any significant impact on the probability of a faulty signal or system shutdown, the number of transfers from main to standby resulting from a fault in a transmitter will be reduced. Also less maintenance will be required to keep the transmitters operating and properly adjusted.

7.4 IMPROVED PEAK DETECTORS

As was discussed in Section 6, the peak detectors in both the localizer and glideslope systems are prone to failures which result in shutdown. These failures are, in part, the result of the approximately 160°F ambient environment maintained by a heater within each peak detector. Also, each peak detector contains attenuator switches which are prone to failure. Clearly, more reliable peak detectors should be installed in the GRN-27 systems.

Southwestern Communications, Inc. is currently testing an improved peak detector design. These improved peak detectors do not contain attenuator switches, and are operated in an environment maintained at 120°F. Although detailed design data have not been made available for a reliability analysis, the improved design should result in much improved reliability.

7.5 LOCALIZER MISALIGNMENT DETECTORS

As described in Section 6.2, the localizer misalignment detectors are prone to corrosion and have a high number of outages in proportion to the number of actual misalignments of the antennas. Improvements in the detector or removal to correct or avoid these problems would reduce the number of unscheduled outages. The course antenna misalignment detector may be considered to serve as a redundant monitor to the far field course alignment monitoring and consequently its removal would have no serious impact on the system hazardous radiation probability.

7.6 IMPROVED INTEGRATED CIRCUITS

Virtually all of the processing in the GRN-27 control unit is performed with NAND gates. A hidden failure in any one of a few critical gates could prevent a transfer to standby upon detection of a faulty signal by the monitors. The probability of such an occurrence would be reduced by the use of higher quality gates. Specifically, using gates of quality level B (as defined in Ref. 4, Pg. 2.1.5-1) would result in hazardous signal probabilities of 0.138×10^{-9} for the localizer or glideslope, assumming a one-week interval between system checks and assuming that landings would not be allowed with an abnormal indication. However, the gates in the GRN-27 are non-standard and not available in a higher quality version. Higher quality gates could be custom designed and manufactured but the cost would be prohibitive.

7.7 FIELD MONITORING OF COURSE WIDTH

As discussed in Section 4, a hazardous signal is the result of a faulty on-course DDM or course width. A faulty on-course DDM is much less probable than a faulty course width because the on-course DDM is monitored in the field (far field for localizer, near field for glideslope) as well as by integral monitors, while the course width is monitored only by integral monitors. Therefore, the probability of hazardous signal is equal to the probability of a signal with faulty course width. If the course width were monitored in the field, the probability of a faulty course width would be as low as the faulty DDM probability.

Monitoring the localizer course width in the field would require placing an antenna to the side of the course centerline, near the far field monitor system. For the glideslope, an antenna would have to be placed above or below the near field monitor antenna. Also additional circuitry would have to be added to process the signals from the new antennas. Such monitoring is used on ILS units in the United Kingdom. However, the implementation of this type of monitoring would be expensive.

8.0 CONCLUSIONS AND RECOMMENDATIONS

As Table 5-1 shows, the proposed ICAO hazardous signal probability limit expected to be recommended for Reliability Level 3 and 4 equipment (0.5×10^{-9}) can be met by the GRN-27 if the following changes are adopted:

1. The transfer capability of the system is tested at least once every 24 hours, and

2. The category of operation is downgraded with an abnormal indication on the remote indicator panel.

It is recommended that the daily test be performed using a remote, semi-automatic test circuit described in Section 7.1.

The GRN-27 meets all ICAO proposed loss of signal probability limits as currently configured and operated.

With the GRN-27 operating on the standby transmitter (that is, as a single transmitter system) the proposed Level 4 loss of signal probability can still be met, although the single transmitter loss of signal probability is approximately five times that of the system with both transmitters available. The hazardous signal probability is the same whether the system is operating with a standby transmitter or not.

The maintenance logs are generally consistent with the theoretical calculations. The largest discrepancy was in the large number of outages attributed to the peak detectors. Replacing the existing peak detectors with an improved design, as discussed in Section 7, could result in a significant reduction in unscheduled outages. Further reduction in the number of outages could be made by correcting the transmitter and localizer misalignment detector problems noted in Section 7. These changes will result in a decreased shutdown probability, but will not appreciably affect the hazardous signal probability.

9.0 REFERENCES

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APPENDIX A

LOCALIZER SUBASSEMBLY FAILURE MODES AND RATES

NOTE: In the failure analysis tables a single asterisk superscript (λ_N^*) indicates that the failure rate for that failure mode is different from the corresponding value for the CAT. III system as given in Ref. 3. A double asterisk superscript (λ_N^{**}) indicates a completely new failure mode. All other failure rates are from Ref. 3.

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda \times 10^6$)	REMARKS
ITEM NAME	I.D. NO.					
Control Unit	01	The control unit processes alarms received from the monitor channels, providing signals to transfer main to standby, to shut down both transmitters, or to indicate a monitor mismatch. In addition, the control unit generates inhibit signals, displays both locally and remotely transmitter status, and displays various power/temperature alarm conditions for both the main shelter and far field monitor. Operational features, such as bypass of monitors, main unit select, memorization of alarms are also associated with the control unit.	Generation of an erroneous transfer signal.	Causes a transfer to standby.	3.18 λ^*_{1A1} (λ^*_{1A2} = 1.829)	λ^*_{1A1} is the failure rate for parts allowing a spontaneous transfer to standby transmitter. λ^*_{1A2} is the failure rate for parts which can fail such that a transfer is made and a persisting transfer signal will cause shutdown.
			Generation of an erroneous shutdown signal due to alarm processing circuitry.	Causes immediate system shutdown.	2.982 λ^*_{1B}	
			Inability to process a transfer signal.	Monitoring of the integral course, sensitivity, I.D., and/or clearance is virtually rendered useless.	2.870 λ^*_{ID} (λ^*_{ID1} = 1.140) (λ^*_{ID2} = 0.913) (λ^*_{ID3} = 1.730)	λ^*_{ID1} is the failure rate for parts allowing faulty signal to persist. λ^*_{ID2} is the part of λ^*_{ID1} including only failures which would not result in an "ABN" or "MONITOR MISMATCH" indication. λ^*_{ID3} is the failure rate for parts preventing transfer and resulting in shutdown upon attempting transfer.
			Inability to process a shutdown signal.	Results in a loss of far field monitoring capability.	1.143 λ^*_{1E}	
			Inability to process any or all power/environmental alarms.	Loss of remote recognition of respective alarm conditions	1.143 λ^*_{1J} (λ^*_{1J} = λ^*_{1E})	

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
ITEM NAME	I.D. NO.					
Control Unit (CONTINUED)	01		Generation of an erroneous control signal that shuts down the main transmitting unit.	The main transmitter is shut down for at least 20 seconds, independent of the persistence of the erroneous control signal.	1.039 λ^*_{1M}	
			Generation of a continuous inhibit to the monitor channels.	The monitor channels are inhibited, and, hence, rendered totally useless. Although the inhibit does not affect the far field monitor channels from alarming, the inhibit does prevent the alarm from being processed in the control unit.	0.232 λ^*_{1S}	
			Inability to process a main inhibit to the monitor channels.	In another failure occurs which initiates a transfer, an immediate shutdown will occur since the monitors are not inhibited during the transition period.	0.545 λ^*_{1T}	
			Loss of +12 volts in control unit power supply. (Note: loss of switched 28v is also included)	All control logic is rendered useless. Both transmitters shutdown; monitor channels, however, are inhibited and, hence, do not alarm.	0.88 λ^*_{1AA}	
Combining Circuits	49	The combining circuits assembly of the far field monitor processes the alarms of the monitor channels, the DC/DC converters, the battery charger and a temperature alarm. This processing includes the time delays necessary for far field monitor channel alarms.	Generation of a shutdown signal	Immediate shutdown of the entire localizer station.	1.345 λ^*_{49E}	
			Inability to process a monitor alarm.	Loss of far field monitoring capability.	1.630 λ^*_{49F}	

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda \times 10^6$)	REMARKS
ITEM NAME	I.D. NO.					
Combining Circuits (CONTINUED)	49		Inability to process an alarm from a single monitor channel.	Effective loss of a far field monitor channel.	0.022 λ^*_{49H}	This failure mode represents the failure of that part of the alarm processing circuitry which is duplicated for each monitor channel. λ^*_{49F} represents the failure of that part of the alarm processing circuitry which is common to both.
			Loss of dc output voltage on +5v regulator.	Immediate shutdown of the entire localizer station, caused by the generation of a shutdown signal from the far field monitor.	0.690 λ_{49M}	

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. No.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda \times 10^6$)	REMARKS
Course Transmitter (MAIN or STANDBY)	02 or 07 (N)	The course transmitter delivers a VHF carrier to the course power amplifier. The carrier is also modulated in the transmitter by the 1020 Hz ID tone and also the low frequency warning signal (when necessary).	Loss of all modulation.	Loss of ID radiation and warning signal capability.	1.446 λ_{NA} = λ_{2A} or λ_{7A}	Transfer would not occur on failure of standby unit. NOTE: λ_N implies the failure rate of each separate item identified in the "I.D. No." column.
			Loss of RF carrier.	Loss of course C+SB and SBO signals.	7.150 λ_{NB}	
Clearance Transmitter (MAIN or STANDBY)	04 or 09	The clearance transmitter delivers a clearance C+SB to the antennas via clearance distribution circuits. In addition, VHF carrier and +18 vdc are fed directly to the sideband generator for the operation of clearance SBO signal.	Loss of all modulation.	Loss of sidebands on the C+SB signal.	1.446 λ_{NA}	Transfer would not occur on failure of standby unit.
			Loss of RF carrier.	Loss of clearance C+SB and SBO signals.	7.150 λ_{NB}	
Sideband Generator (MAIN or STANDBY)	05 or 08	Provides clearance SBO signal to the sideband amplifier.	Loss of output signal.	Loss of clearance SBO signal.	10.250 λ_N	Transfer would not occur on failure of standby unit.
Modulator (MAIN or STANDBY)	03 or 08	Provides course VHF carrier amplitude modulated by a 90 Hz and 150 Hz signal, CSE C+SB. It provides the course SBO signal; A LOW frequency 90+150 Hz signal which feeds the clearance transmitter; and a 90-150 Hz signal feeding the sideband generator.	Loss of low freq. oscillator (14.4 KHz) resulting in loss of all 90 Hz and 150 Hz modulation.	Loss of the following system signals: 1. LF 90+150 2. SB in clearance C+SB 3. LF 90-150 4. Clearance SBO 5. Course SBO 6. SB in course C+SB	2.413 λ_{NA}	Transfer would not occur on failure of standby unit.
			Loss of VHF carrier to digital phasing ckts (to either or both of the 90 & 150 phase shifters).	Loss of SB in course C+SB signal & course SBO signal.	0.413 λ_{NB}	

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
ITEM NAME	I.D. No.					
Modulator (Continued)	03 or 08		Loss of 90 or 150 dividers, synchronization circuitry or 90/150 Hz shift registers.	Out of tolerance course and clearance C+SB and SBO signals.	1.453 λ_{NC}	
			Loss of $\lambda/32$ driving signal to delay line (either the 90 Hz or 150 Hz phase shifter).	Slight distortion of the course C+SB and SBO signals.	2.426 λ_{ND}	Not Hazardous.
			Loss of $\lambda/16$ driving signal to the delay lines (either the 90Hz or 150 Hz phase shifter).	Distortion somewhat more than $\lambda/32$ of the course C+SB and SBO signals.	2.426 λ_{NE}	Not Hazardous.
			Loss of $\lambda/8$, $\lambda/4$, $\lambda/4$, $\lambda/2$ or $\lambda/2$ signal to the delay line. (either the 90 Hz or 150 Hz phase shifter).	Out of tolerance course C+SB and SBO signals.	12.832 λ_{NF}	
			Loss of +90, -90, +150 or -150 Hz phase shifter RF signal.	Out of tolerance course C+SB and SBO signals.	1.302 λ_{NG}	
			Loss of +90, -90, +150, or -150 Hz phase shifter RF signal.	Out of tolerance SBO signal.	0.5234 λ^{**}_{NG1}	
			Loss of either 90 Hz or 150 Hz sinusoidal signal for clearance transmission.	Out of tolerance clearance C+SB & SBO signals.	1.552 λ_{NH}	

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. No.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
Modulator (Continued)	03 or 08		Loss of 90+ 150 Hz signal	Loss of modulation for clearance transmitter resulting in SB loss of clearance C+SB.	0.388 λ_{NI}	
			Loss of 90-150 Hz signal	Loss of clearance SBO signal	0.756 λ_{NJ}	
Course Monitor CHANNELS (1 or 2)(MAIN)	35 or 36	Provide monitoring of the course position (DDM), the % modulation (SDM), and the course RF power level.	Loss of monitoring ability, producing alarms	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control (transmitter transfer capability)	13.539 λ^*_{NA}	If another corresponding monitor alarm failure occurs in the remaining monitor, localizer will transfer, then shut down.
			Loss of monitoring ability, producing no alarms.	Loss of 1 of 2 monitors. Now dependent upon remaining monitor for system control.	5.62 λ^*_{NB}	If the same failure occurs in the remaining monitor, hazardous radiation will go undetected.
Clearance Monitor CHANNELS (1 or 2)	43 or 44	Provide monitoring of the clearance DDM, % modulation, and clearance RF power level.	Loss of monitoring ability producing alarms.	Loss of 1 of 2 monitors. Now dependent upon remaining monitor for system control.	14.509 λ^*_{NA}	If another corresponding monitor alarm failure occurs in the remaining monitor, localizer will transfer, then shut down.
			Loss of monitoring ability producing no alarm.	Loss of 1 of 2 monitors. Now dependent upon remaining monitor for system control.	5.78 λ^*_{NB}	If the same failure occurs in the remaining monitor, hazardous radiation will go undetected.
I.D. Unit (Main or Standby)	06 or 11	Provides a keyed 1020 Hz audio signal (ID TONE) to aircraft for runway & approach identification.	Loss of ID signal (audio)	Transfer to standby unit.	3.949 λ_{NA}	Transfer would not occur on failure of standby unit.
			Loss of code or keying.	Transfer to standby unit.	13.134 λ_{NB}	

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x 10^6$)	REMARKS
ITEM NAME	I.D. No.					
Course Peak Detector	20	The course peak detector receives a simulated course position input signal. This input signal is obtained by a combination of signals obtained by proximity probes at the radiating antennas. The peak detector then converts the RF signal into a low-frequency signal, both DC and AC. The DC is representative of the RF power; the AC is the demodulated 90/150/1020 Hz signal.	Total loss of output signal (both AC and DC)	Loss of input to monitor channels, causing transfer, then shutdown.	0.787 λ_{20A}	
			Incorrect (low) DC output signal.	The monitor channels process the failure as being a drop in course RF power and an increase in modulation percentage, causing transfer, then shutdown.	0.386 λ_{20B}	
Sensitivity Peak Detector	23	The sensitivity peak detector receives a simulated input signal, representative of the course width (displacement sensitivity). This input is obtained by a combination of signals obtained by proximity probes at the radiating antennas. The peak detector converts the RF signal into a low frequency signal, both DC and AC. The DC is representative of the RF power; the AC is the demodulated 90/150 Hz signal.	Total loss of output signal (both AC and DC)	Loss of input signal to the sensitivity monitor channels, causing transfer then shutdown.	0.789 λ_{23A}	
			Incorrect (low) DC output signal.	The monitor channels process the signal as being a drop in course RF power, an increase in modulation percentage, and an decrease in DDM, causing transfer then shutdown.	0.386 λ_{23B}	
Clearance Peak Detector	26	The clearance peak detector receives a simulated clearance input signal. This input signal is obtained by a combination of signals obtained from both proximity probes and a sampled signal of clearance C+SB and SBO. This RF input signal is converted to a low-frequency signal, both AC & DC. The DC is representative of the clearance RF power; the AC is the demodulated 90/150 Hz clearance signal.	Total loss of output signal (both AC and DC).	Loss of input signal to clearance monitors, causing transfer, then shutdown.	0.789 λ_{26A}	
			Incorrect (low) DC output signal.	The monitor channels process the failure as being a drop in clearance RF power, an increase in DDM, causing transfer then shutdown.	0.386 λ_{26B}	
Sensitivity Monitor CHANNELS (1 or 2)(MAIN)	38 or 39	Provide monitoring of the course width (DDM).	Loss of monitoring ability producing alarms.	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control.	9.596 λ^*_{NA}	If another corresponding monitor DDM failure occurs in remaining monitor, transfer, then shutdown will result.

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
ITEM NAME	I.D. No.					
Sensitivity Monitor CHANNELS (1 or 2) (MAIN) (CONTINUED)	38 or 39		Loss of monitoring ability producing no alarms.	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control.	3.12 λ^*_{NB}	Only DDM monitoring circuitry is critical. If the same failure occurs in the remaining monitor, hazardous radiation will go undetected.
Identification Monitor Assembly (I.D. Monitors No. 1 or 2)	34	Each I.D. monitor receives its respective input from the AGC outputs of the integral course position monitor channels. Each I.D. monitor checks its input signal for the presence of a keyed (coded) audio (1020 Hz) tone. An alarm is produced whenever a loss of audio or keying exists over a definite time interval.	Loss of monitoring ability of one of the main I.D. monitors, producing an alarm.	Loss of 1 of 2 I.D. monitors. Now dependent on remaining I.D. monitor for system control.	5.742 (total) λ_{34A1} = λ_{34A2} = λ_{34A3} = 1.914	If another such failure occurs in the I.D. monitor, the system will immediately transfer and then shut down.
			Loss of monitoring ability of one of the main I.D. monitors, producing no alarm.	Loss of 1 of 2 I.D. monitors. Now dependent on remaining monitor for system control.	1.050 λ_{34B}	Not hazardous. The I.D. signal is assumed non-essential.
Identification Monitor Assembly (Regulator/ Alarm Logic)	34	The I.D. monitor assembly contains the two I.D. monitors. A common voltage regulator (+12, +15, -12V) supplies power to both monitors. Alarm logic is also contained within this assembly.	Loss of +12 volts of regulator.	All I.D. monitors are rendered useless. No alarms are produced and, hence, operation continues. I.D. signal monitoring is totally lost.	0.423 λ_{34E}	Not hazardous. I.D. signal assumed not critical.
			Loss of +15 volts of regulator.	I.D. alarm outputs go to a "high" logic level. The control unit processes this as an immediate transfer & then a shutdown.	0.137 λ_{34F}	
			Loss of -12 volts of regulator.	Alarms on all I.D. monitors causing an immediate transfer and then a shutdown.	0.290 λ_{34G}	
			Alarm logic causing a main I.D. alarm.	The control unit processes this as an immediate transfer and then a shutdown.	0.262 λ_{34H}	

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. NO.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
Identification Monitor Assembly (Regulator/ Alarm Logic) (CONTINUED)	34		Alarm logic inhibiting the main I.D. alarm.	Loss of main I.D. monitoring ability.	0.434 λ_{34I}	Not hazardous - I.D. signal assumed not critical.
			Alarm logic inhibiting the main I.D. alarm.	Shutdown of standby transmitting unit.	0.172 λ_{34J}	
			Alarm logic inhibiting the standby I.D. alarm.	Loss of standby I.D. monitoring ability.	0.242 λ_{34K}	Hazardous - λ_{34K} is similar to λ_{34D}
			Alarm logic causing a mismatch.	No serious effect on system.	0.160 λ_{34L}	Not hazardous.
Changeover and Test Circuits (Peak Detectors Excluded)	12	The changeover and test circuits provide the automatic changeover capability for the redundant transmitting units. It selects upon command from the control unit which transmitting unit radiates into the antennas and which unit operates into dummy loads	Inability to changeover transmitting units by switching circuitry.	Any failure on the main unit, which should only generate a changeover to standby, will result in a system shutdown.	0.221 λ_{12A}	Essentially renders the standby unit useless.
			Premature transfer of transmitting units to antennas by switching circuity.	If in MAIN, a transfer to STANDBY will occur; if in STANDBY, a transfer to OFF will occur. This is due to a momentary loss of signal.	0.134 λ_{12B}	Essentially renders either the main or standby transmitter useless.
			Total loss (or incorrect phasing of course SBO signal of the main transmitting unit.	Alarms on monitor channels initiate a transfer to standby and system operates on standby.	0.065 λ^*_{12D}	

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. NO.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x 10^6$)	REMARKS
Changeover & Test Circuits (CONTINUED)	12		Total loss (or incorrect phasing) of clearance SBO signal of the main transmitting unit.	Alarms on the clearance monitors initiate a transfer to standby & system operates on standby.	0.070 λ_{12E}	
			Loss of any one or all of CSE C+SB, CSE SBO, CL C+SB, CL SBO, (to main transmitter)	Immediate shutdown after an automatic transfer.	2.417 λ_{12F} (Total) λ_{12F1} = 1/2 λ_{12F} = 1.209	λ_{12F} includes both the course and clearance failure rates.
Course Distribution Circuits	13	The course distribution circuit distribute the course C+SB & SBO signals to the antennas.	A total loss of signal for any signal path; incorrect phasing of either of the radiated signals; distortion sufficient to cause monitor alarms.	Since a failure of this type is independent of the transmitting unit, an immediate shutdown after an automatic transfer will result.	0.961 λ_{13}	Since any signal degradation sufficient to be "out of tolerance" has the same net effect, all possible failure modes may be treated on an aggregate basis.
			Loss of SBO.	Immediate shutdown after transfer.	0.229 λ^{**}_{13A}	
Clearance Distribution Circuits	14	The clearance distribution circuits route and distribute the clearance C+SB & SBO signals to the antennas.	A loss (or major distortion) of signal for any clearance signal path.	Upon failure, an immediate transfer followed by an immediate shutdown will occur.	0.194 λ_{14}	SDM,DDM and/or RF alarms on the monitors are dependent upon specific failure characteristics.
Battery Charger	15	The battery charger supplies all the dc power to all the equipment of the localizer station. (The far field monitor has its own power source) In addition to supplying the power to the electronic equipment, the battery charger ensures that a full charge is constantly maintained on both batteries.	Loss of charger output voltage. (Note: the nominal output voltage is 30 volts DC)	System will operate 3 hrs on batteries after charger failure.	10.477 λ_{NA}	

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. No.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x 10^6$)	REMARKS
Battery Charger (CONTINUED)	15	In the event of a primary power failure, the two batteries (in parallel) supply the necessary dc power.	Charger failure indication only while output voltage is still maintained on charger.	No immediate effect on system operation.	0.801 λ_{NB}	Not hazardous; both transmitters still available after downgrade.
			Loss of equalize voltage capability, either manual and/or automatic. Note: the equalize voltage is a nominal 33 volts dc, thus providing a "hard charge" to the batteries.	No immediate effect on system operation.	6.436 λ_{NC}	Not hazardous; a total discharge of the batteries can occur only after the system is operated on batteries for some extended period of time (greater than three hrs). System operation on batteries is a result of either primary power supply failure or a failure of charger.
DC/DC Converter (No. 1 or 2)	17 or 18	Each of the DC/DC converters transforms the +30 volts nominal input voltage to three different output voltages: +5, 5v, -18v, & -50v. The output voltages of each converter are respectively used in parallel and feed both modulators in the system.	Loss of any one or all the following voltages: +5,5v, -18v, -50v.	Station maintains normal operation on remaining converter voltages. Each of the converter voltages is sensed in the control unit for abnormal tolerances.	6.598 λ_N	To result in a station shutdown, both converters must fail.
Temp Sensors	19	The temperature sensors provide alarm indications whenever the temperature exceeds or drops below preset limits. These limits are set to give indication of air conditioner/heater failures.	Failure producing an alarm indication.	Immediate shutdown of localizer station.	0.100 λ_{19A}	Temperature alarm is optional for CAT. II.
			Failure producing no alarm indication.	There are 2 sensors (thermocouples)-one for high temps & one for low. A failure of this type in	0.100 λ_{19B}	Not hazardous. If temperature affects system operation, other alarms will occur.

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE (λx10)	REMARKS
ITEM NAME	I.D. No.					
Temp Sensors (CONTINUED)	19		Failure producing no alarm indication. (CONTINUED)	one of the sensors does not affect the operation of the other. Hence, the only effect is the loss of temp. monitoring ability for only one temp. extreme (high or low).		
DC/DC Converter (No. 1 or No. 2) (FFM)	51 or 52	Each of the DC/DC converters of the far field monitor provides -18v, used in the monitor channels and the receivers. They are in parallel and isolated by diodes.	Loss of -18v output.	System maintains operation on remaining converter. If the remaining converter also fails, the localizer station will shut down, due to monitor channel alarms.	2.412 λ_{NA}	
			Generation of an erroneous converter fail alarm.	"Abnormal" indication at remote control panel.	0.050 λ_{NB}	Not hazardous; both converters still operational
Battery Charger	50	The battery charger supplies +24 volts to each of the units at the far field monitor - the two converters, the three receivers and their respective monitor channels, and the combining circuits assembly. The battery charger also keeps a full charge on the battery at all times.	Loss of +24 volts output.	System maintains operation on far field monitor battery.	5.790 λ_{50A}	
			"Low voltage" battery disconnect circuit failure, disconnecting the battery from the load	If another failure of the battery charger causing loss of +24 v occurs, immediate shutdown of the localizer station will result.	0.519 λ_{50B}	Note failure mode has the same effect as an ffm battery failure.
			Loss of equalize charge capability after a power outage.	Does not affect system operation. A trickle charge will still be applied to the battery.	0.318 λ_{50C}	Not hazardous. "Quick charge" capability does not directly affect monitoring performance.
			Generation of an erroneous charger fail alarm.	"Abnormal" indication at remote control panel.	0.126 λ_{50D}	Not hazardous; far field monitoring not affected.

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. No.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
Battery Charger (CONTINUED)	50		Continuous equalize voltage only	Far field monitor maintains normal operation at a slightly higher supply voltage.	7.658 λ_{50E}	Not hazardous; preventive maintenance required for battery check.
Receiver No. 1 or No. 2	53 or 54	Each of the far field monitor receivers receives a low level rf input signal and converts it to the ILS audio and dc signal which is then the input to the respective monitor channel. The DDM of the audio signal is representative of the far field course position.	Total loss of output signal or any major signal distortion.	Loss of the input signal to the corresponding far field monitor channel will produce a FFM monitor mismatch. Loss of 1 of 2 FFM monitors. Now dependent on remaining monitor for system operation.	6.879 λ_N	The SDM strap option provided remote recognition of failure.
Monitor Channels No. 1 or 2	56 or 57	To provide monitoring of the course position in the far field region of the runway.	Loss of monitoring ability.	Loss of 1 of 2 monitors. Now dependent on remaining monitor.	0.825 λ_{NA}	
			Loss of monitoring ability, producing DDM alarm.	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system operation.	11.099 λ_{NB}	
			Loss of monitoring ability producing no alarm	Loss of 1 of 2 monitor voting capability. Now dependent on remaining monitor for far field monitoring.	4.422 λ_{NC}	
Temp. Sensor	59	Monitors the temperature of the FFM for out of tolerance conditions.	Generation of an erroneous temp. alarm.	"Abnormal" indication at remote control panel.	0.050 λ_{59A}	Not hazardous; far field monitoring still available
			Inability to produce a temp. alarm.	Loss of temp. monitoring ability without recognition.	0.050 λ_{59B}	Not hazardous; if temperature affects monitoring, alarms will occur.

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
ITEM NAME	I.D. NO.					
Course Power Amplifier	60 or 61	Deliver an amplified UHF carrier to the modulator. The carrier is modulated in the transmitter by the 1020 Hz I.D. tone and the low frequency warning signal.	Loss of RF carrier.	Loss of course C+SB and SBO signals.	4.727 λ_N	
Course Power Amplifier Power Supply	62 or 63	Provides 1020 Hz modulated +20 volts to course power amplifier.	Loss of +20 volts.	Loss of course C+SB and SBO signals.	9.984 λ_{NA}	
			Loss of all modulation.	Loss of I.D. radiation and warning signal capability.	0.493 λ_{NB}	
Sideband Amplifier	64 or 65	Provides clearance SBO signal to the sideband amplifier.	Loss of output signal.	Loss of clearance SBO signal.	2.631 λ_N	
Course Re-Combination Circuits	66	Constructs the signals used for monitoring course position, course width, percent modulation and RF power.	Failure causing a loss (or incorrect) of signal to the on course or course sensitivity monitors.	Upon failure, an immediate transfer followed by an immediate shutdown will occur.	1.116 λ_{66}	Since any signal degradation sufficient to be out of tolerance has the same net effect, all possible failure modes may be treated on an aggregate basis.
Clearance Re-Combination Circuits	67	Constructs the signals for monitoring the clearance DDM, percent modulation, and RF power.	Failure causing a loss (or incorrect) signal to the clearance monitors.	Upon failure, an immediate transfer followed by an immediate shutdown will occur.	0.311 λ_{67}	SDM, DDM, and/or RF alarms on the monitors are dependent on specific failure characteristics.
Course Antenna Array	68	Radiate the course position signal.	Failure causing a loss (or incorrect) signal to the course monitors.	Upon failure, an immediate transfer followed by an immediate shutdown will occur.	1.347 λ_{68}	

TABLE A. LOCALIZER FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
ITEM NAME	I.D. NO.					
Clearance Antenna Array	69	Radiates the clearance signals.	Failure caus- a loss (or incorrect) signal to the clear- ance monitor	Upon failure, an immediate transfer fol- lowed by an immediate shut- down will occur	0.615 λ_{69}	

APPENDIX B

GLIDESLOPE SUBASSEMBLY FAILURE MODES AND RATES

NOTE: In the failure analysis tables a single asterisk superscript (λ_N^*) indicates that the failure rate for that failure mode is different from the corresponding value for the CAT. III system as given in Ref. 3. A double asterisk superscript (λ_N^{**}) indicates a completely new failure mode. All other failure rates are from Ref. 3.

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
ITEM NAME	I.D. NO.					
Control Unit	01	The control unit processes alarms received from the monitor channels, providing signals to transfer main to standby, to shut down both transmitters, or to indicate a monitor mismatch. In addition, the control unit generates inhibit signals, displays both locally and remotely transmitter status, and displays various power/temperature alarm conditions. Operational features, such as bypass of monitors, main unit select, and memorization of alarms are also associated with the control unit.	Generation of an erroneous transfer signal.	Causes a transfer to standby.	3.18 λ^*_{1A1} (λ^*_{1A2} = 1.829)	λ^*_{1A1} is the failure rate for parts allowing a spontaneous transfer to standby transmitter. λ^*_{1A2} is the failure rate for parts which can fail such that a transfer is made & a persisting transfer signal will cause shutdown.
			Generation of an erroneous shutdown signal due to alarm processing circuitry.	Immediate system shutdown.	2.982 λ^*_{1B}	
			Inability to process a transfer signal.	Monitoring of the integral course, sensitivity, I.D., and/or clearance is virtually rendered useless.	2.870 λ^*_{1D} (λ^*_{1D1} = 1.140) (λ^*_{1D2} = 0.913) (λ^*_{1D3} = 1.730)	λ^*_{1D1} is the failure rate for parts allowing faulty signal to persist. λ^*_{1D2} is the part of λ^*_{1D1} including only failures which would not result in an "ABN" or "MONITOR MISMATCH" indication. λ^*_{1D3} is the failure rate for parts preventing transfer & resulting in shutdown upon attempting transfer.
			Inability to process any or all power/environmental alarms.	Loss of remote recognition of respective alarm conditions.	1.143 λ^*_{1J}	

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. NO.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
Control Unit (CONTINUED)	01		Generation of an erroneous control signal that shuts down the main transmitting unit	The main transmitter is shut down for at least 20 sec. independent of the persistence of the erroneous control signal	1.039 λ^*_{1M}	
			Generation of a continuous inhibit to the monitor channels.	The monitor channels are inhibited and, hence, rendered totally useless.	0.232 λ^*_{1S}	
			Inability to process a main inhibit to the monitor channels.	If another failure occurs which initiates a transfer, an immediate shutdown will occur since the monitors are not inhibited during the transition period.	0.545 λ^*_{1T}	
			Loss of +12 volts in control unit power supply. (Note: loss of switched 28v is also included.)	All control logic is rendered useless. Both transmitters shut down; monitor channels, however, are inhibited and, hence, do not alarm.	0.88 λ^*_{AA}	

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda \times 10^6$)	REMARKS
ITEM NAME	I.D. NO.					
Control Unit (CONT.)	01		Inability to process near field monitor alarms in delay circuit cards.	Loss of near field monitoring capacity.	0.262 λ_{1X}^{**}	
			Inability to process a monitor mismatch condition, failing to generate an "abnormal" indication at the remote control panel.	No remote indication of a monitor mismatch condition.	2.043 λ_{1Y}^{**}	
			Inability to process an antenna misalignment alarm, failing to generate an "abnormal" indication at the remote control panel.	No remote indication of an antenna misalignment.	0.908 λ_{1Z}^{**}	

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. NO.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
Course Transmitter (MAIN or STANDBY)	02 or 06 (N)	The course transmitter in conjunction with the 10 watt amplifier delivers a UHF carrier to the modulator.	Loss or degradation of UHF carrier.	Loss of all course signal radiation, affecting the entire glidepath angle and width.	6.734 λ_N	Transfer would not occur on failure of stand-by unit.
Clearance Transmitter (MAIN or STANDBY)	04 or 08	The clearance transmitter supplies a UHF carrier modulated at 150 Hz which is used to ensure low approach angle coverage.	Loss or degradation of the 150 Hz modulation.	Loss of clearance coverage of approach angle. (Pure carrier radiated).	1.914 λ_{NA}	Transfer would not occur on failure of stand-by unit.
			Loss or degredation of UHF carrier.	Loss of clear-coverage of approach angle.	6.734 λ_{NB}	
10 Watt Amplifier (MAIN or STANDBY)	05 or 09	the 10 watt amplifier merely amplifies the course UHF carrier.	Loss or degradation of UHF carrier.	Loss of all course signal radiation.	0.686 λ_N	Transfer would not occur on failure of stand-by unit.
Modulator (MAIN or STANDBY)	03 or 07	Provides course UHF carrier amplitude modulated by a 90Hz and 150 Hz signal, CSE C+SB. It provides the course SBO signal; a low frequency 150 Hz signal which feeds the clearance transmitter. (Two frequency glideslope only: no clearance signal from the one frequency glideslope).	Loss of low frequency oscillator (14.4 kHz) resulting in loss of all 90Hz and 150 Hz modulation.	Loss of the following system signals: 1. LF 150 2. SB in clearance C+SB 3. Course SBO 4. SB in course C+SB	2.613 λ_{NA}	Transfer would not occur on failure of stand-by unit.
			Loss of UHF carrier to digital phasing ckts. (to either or both of the 90 and 150 phase shifter)	Loss of SB in course C+SB signal and course SBO signal.	0.427 λ_{NB}	
			Loss of 90 or 150 Hz dividers, synchronization circuitry or 90/150 Hz shift registers.	Out of tolerance course C+SB and SBO, and, for two frequency glideslope, clearance C+SB signals.	1.453 λ_{NC}	

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION		FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
ITEM NAME	I.D. NO.					
Modulator (MAIN or STANDBY) (CONTINUED)	03 or 07		Loss of λ_{32} driving signal to delay line (either the 90Hz or 150 Hz phase shifter)	Slight distortion of the course C+SB and SBO signals.	2.426 λ_{ND}	Not hazardous.
			Loss of λ_{16} driving signal to the delay lines (either the 90 Hz or 150 Hz phase shifters).	Distortion somewhat more than 32 of the course C+SB and SBO signals.	2.426 λ_{NE}	Not hazardous.
			Loss of λ_8, λ_4, $\bar{\lambda}_4$, λ_2, or $\bar{\lambda}_2$ signal to the delay line, (either the 90 Hz or 150 Hz phase shifters)	Out of tolerance course C+SB and SBO signals.	12.832 λ_{NF}	
			Loss of +90, -90, +150, or -150 Hz phase shifter RF signal.	Out of tolerance C+SB signal.	1.302 λ_{NG}	
			Loss of +90, -90, +150, or -150 Hz phase shifter RF signal.	Out of tolerance SBO signal.	0.5234 λ^{**}_{NG1}	
			Loss of the 150 Hz sinusoidal signal for clearance transmission.	Out of tolerance clearance C+SB signal.	1.176 λ_{NH}	The one frequency glideslope does not radiate a clearance signal.
Course Monitor Channels (1 or 2) (MAIN)	34 or 35	Provide monitoring of the course position path angle (DDM), the % modulation (SDM) and the course UHF power level.	Loss of monitoring ability producing alarms.	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control.	12.918 λ^*_{NA}	If another corresponding monitor alarm failure occurred in the remaining monitor, glideslope will transfer, then shutdown.
			Loss of monitoring ability producing no alarms.	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control.	5.065 λ^*_{NB}	If the same failure occurs in the remaining monitor, hazardous radiation will go undetected.

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. NO.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
Sensitivity Monitor Channels (1 or 2) (MAIN)	37 or 38	Provide monitoring of the course width (DDM)	Loss of monitoring ability producing alarms.	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control	9.596 λ^*_{NA}	If another corresponding DDM failure occurs in the remaining monitor, glideslope will transfer, then shutdown.
			Loss of monitoring ability producing no alarms.	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control	3.121 λ^*_{NB}	If the same failure occurs in the remaining monitor, hazardous radiation will go undetected.
Near Field Monitor Channels 1 or 2	43 or 44	Provide monitoring of the near field course position path angle (DDM)	Loss of monitoring ability producing alarm.	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control	11.099 λ_{NA}	If another corresponding monitor alarm failure occurred in the remaining monitor, immediate glideslope shutdown will result.
			Loss of monitoring ability producing no alarm.	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control	3.822 λ_{NB}	If the same failure occurs in the remaining monitor, hazardous radiation will go undetected.
Clearance Monitor (Channels 1 or 2) (MAIN)	40 or 41	Provide monitoring of of the clearance DDM, % modulation, and clearance UHF power level. (Two frequence glideslope only. No clearance signal from the one frequency glideslope).	Loss of monitoring ability producing alarm	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control	13.273 λ^*_{NA}	If another corresponding monitor alarm failure occurred in the glideslope will transfer, then shutdown.
			Loss of monitoring ability producing no alarm.	Loss of 1 of 2 monitors. Now dependent on remaining monitor for system control	5.077 λ^*_{NB}	If the same failure occurs in the remaining monitor, hazardous radiation will go undetected.
Near Field Peak Detector	28	The near field peak detector receives its input signal from a near field antenna. The received RF signal is representative of the course alignment. The peak detector then converts to the RF signal into a low-frequency signal, both DC & AC. The DC is representative of the course RF power; the AC is the demodulated 90/150 Hz course signals.	Loss of detected output signal.	Loss of the input signal to the near field monitor channels, causing a shutdown.	1.115 λ_{28}	

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. NO.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
Course Peak Detector	19	The course peak detector receives a simulated course position input signal. This input signal is obtained by a combination of signals obtained by proximity probes at the radiating antennas. The peak detector then converts the RF signal into a low frequency signal, both DC and AC. The DC is representative of the RF power; the AC is the demodulated 90/150 Hz signal.	Loss of detected output signal.	Loss of input to monitor channels, causing transfer, then shutdown.	1.115 λ_{20A}	
Sensitivity Peak Detector	22	The sensitivity peak detector receives a simulated input signal, representative of the course width (displacement sensitivity). This input is obtained by a combination of signals obtained by proximity probes at the radiating antennas. The peak detector converts the RF signal into a low-frequency signal, both DC and AC. The DC is representative of the RF power; the AC is the demodulated 90/150 Hz signal.	Loss of detected output signal.	Loss of input signal to the sensitivity monitor channels, causing transfer, then shutdown.	1.115 λ_{22}	
Clearance Peak Detector	25	The clearance peak detector receives a simulated clearance input signal. This input signal is obtained by a combination of signals obtained from both proximity probes and a sampled signal of clearance C+SB and SBO. This RF input signal is converted to a low frequency signal, both AC and DC. The DC is representative of the clearance RF power; the AC is the demodulated 90/150 Hz clearance signal. (Two frequency glideslope only. No clearance signal from the one frequency glideslope).	Loss of detected output signal.	Loss of input signal to clearance monitors, causing transfer, then shutdown.	1.115 λ_{25}	

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. NO.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
Changeover and Test Circuits (Peak Detector Excluded)	10	The changeover and test circuits provide the automatic changeover capability for the redundant transmitting units. It selects upon command from the control unit which transmitting unit radiates into the antennas.	Inability to changeover transmitting units by switching circuits.	Any failure on the main unit, which should only generate a changeover to STANDBY, will result in a system shutdown.	0.221 λ_{10A}	Essentially renders the standby unit useless.
			Premature transfer of transmitting units to antennas by switching circuits.	If in MAIN, a transfer to STANDBY will occur; if in STANDBY, a transfer to OFF will occur. This is due to momentary loss of signal.	0.134 λ_{10B}	Essentially renders either the Main or Standby transmitters useless.
			Total loss (or incorrect phasing) of course SBO signal of the main unit.	Alarms on monitor channels initiate a transfer to standby and system operates on standby.	0.2750 λ^{**}_{10D} (2 freq. or side band ref.)	λ^{**}_{10D} = 0.2851 for null reference glideslope.
			Loss of any one or all of: CSE C+SB, CSE SBO, CL C+SB, (to main transmitter). (No CL in one frequency glideslope).	Immediate shutdown after an automatic transfer.	1.951 λ_{10E} = λ_{10E1} 0.466 (Each pin switch circuit)	
Distribution Circuits (Antennas Included)	11	The UHF distribution circuits combine and distribute the CSE C+SB, CSE SBO, and CL C+SB signals to the three 2-lambda antennas. (No CL signal from null reference or side band reference glideslope).	A loss, degradation or incorrect phasing of any signal feedings any one of the three antennas.	Since a failure of this type is independent of the transmitting unit (signal paths common to both transmitters), an immediate shutdown after an automatic transfer will occur.	1.231 λ_{11} (2 freq.) (λ_{11} = 0, null ref., λ_{11} = 0.635 side band ref.) λ^{**}_{11A} = 0.0101	λ^{**}_{11A} is the failure rate for degradation of SBO signal only.

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. NO.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
UHF Recombining Circuits and Probes (Peak Detectors Excluded)	12	The UHF recombining circuits, receiving input from proximity detector probes, combine the CSE C+SB, CSE SBO and CL C+SB to provide inputs to monitors for monitoring the course position, displacement sensitivity and clearance radiation. (No CL signal from one frequency glideslope).	A loss, degradation or incorrect phasing of an signal feeding any of the monitors.	The actual field radiation is unaffected. However, the monitor channels believe an "out of tolerance" condition exists and initiate a transfer; since the circuitry is common to both transmitting units, the monitors will again sense an "out of tolerance" condition and initiate a shutdown.	0.778 λ_{12}	
Near Field Antenna and Power Splitter (Peak Detectors Excluded)	18	Provides the input for the three near field monitors.	A loss or degradation of signal feeding the monitors.	The erroneous (or total loss of) signal is processed as a near field alarm, resulting in transfer and shutdown after the nominal time delay.	0.098 λ_{18}	

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. NO.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
Battery Charger	13 or 14	The battery charger supplies all the electric power to all the equipment of the glideslope station. In addition, to supplying the power to the electronic equipment, it ensures that a full charge is constantly maintained on both batteries. In the event of a primary power failure, the two batteries (in parallel) supply the necessary DC power.	Loss of charge output voltage (note: the nominal output voltage is 30 volts DC)	System will operate 3 hours on batteries after charger failure.	10.477 λ_{NA}	Not hazardous; redundancy of remaining charger and the two batteries provide negligible probability of station shutdown.
			Charger failure indication only while output voltage is still maintained on charger.	No immediate effect on system operation.	0.801 λ_{NB}	Not hazardous; both transmitters still available after downgrade.
			Loss of equalize voltage capability - either manual and/or automatic. (note: the equalize voltage is a nominal 33 volts DC thus providing a "hard charge" to the batteries.	No immediate effect on system operation.	6.436 λ_{NC}	Not hazardous; a total discharge of the batteries can occur only after the system is operated on batteries for some extended period of time (greater than 3 hrs). System operation on batteries is a result of either primary power failure or a charger failure.
DC/DC Converter No. 1 or 2	15 or 16	Each of the DC/DC converters transforms the +30 volts nominal input voltage to 3 different output voltages: +5.5V, -18V, and -50V. The output voltages of each converter are respectively used in parallel and feed both modulators in the system.	Loss of any one or all of the following voltages: +5.5V, -18V, -50V.	Station maintains normal operation on remaining converter voltages Each of the converter voltages is sensed in the control unit for abnormal tolerances.	6.598 λ_N	To result in a station shutdown, both converters must fail.
Temp Sensors	17	The temperature sensors provide alarm indications whenever the temperature exceeds or drops below pre-set limits. These limits are set to give indication of air-conditioner/heater failures.	Failure producing an alarm indication.	Immediate shutdown of glideslope station.	0.100 λ_{17A}	Temperature alarm is optional for CAT. II.

TABLE B. GLIDESLOPE FAILURE ANALYSIS

IDENTIFICATION						
ITEM NAME	I.D. NO.	FUNCTION	FAILURE MODE	FAILURE EFFECT	FAILURE RATE ($\lambda x10^6$)	REMARKS
Temp Sensors (CONTINUED)	17		Failure producing no alarm indication.	There are two sensors (thermocouples)- one for high temps and one for low temps. A failure of this type in one of the sensors does not affect the operation of the other. Hence, the only effect is the loss of temp. monitoring ability for only one temperature extreme (high or low).	0.100 λ_{17B}	Not hazardous; if temperature affects system operation, other alarms will occur.
Misalignment Detector	49	The misalignment detector detects permanent misalignment or deformation of the glideslope antenna tower. A nominal 135 seconds delay is provided to process alarms, since tower vibrations and wind loadings can occur.	Loss of alignment detection producing an alarm.	Erroneous shutdown of the glideslope station.	4.915 λ_{49A}	
			Loss of alignment detection producing no alarm.	Although the near field monitors detect field radiation, an erroneous signal radiation can still exist since tower misalignment in the horizontal plane chiefly affects the width of the glide path angle and the clearance radiation.	2.354 λ_{49B}	

APPENDIX C

LOCALIZER FAULTY SIGNAL AND SHUTDOWN PROBABILITY CALCULATIONS

1. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION DDM SIGNAL DUE TO EQUIPMENT FAILURE.

CALCULATION

$$P_{CSE_{DDM}} = (P_{CF} \times P_{INT_{CSE_{DDM}}} \times P_{MON_{FF}} \times P_{XMTR_{CSE_{DDM}}}) + P_{FF_{DELAY}}$$

WHERE

$$P_{CF} = \frac{P_{MON_{FF}} \times P_{INT_{CSE_{DDM}}}}{P_{XMTR_{CSE_{DDM}}} + (P_{MON_{FF}} \times P_{INT_{CSE_{DDM}}})}$$

P_{CF} is a conditional factor, expressing the fact that all DDM monitoring must be lost before radiation of a faulty DDM signal in order for such a signal to be undetected.

$$P_{INT_{CSE_{DDM}}} = (\lambda_{MON_{CSE}} \cdot MI)^{MM} + \lambda_{1MON} \cdot MI$$

$P_{INT_{CSE_{DDM}}}$ is the probability of failure of course integral monitoring circuitry (hidden failure).

$$P_{MON_{FF}} = (\lambda_{MON_{FF}} \cdot MI)^2 + (\lambda^*_{49F} + \lambda^*_{1E}) \times MI$$

$P_{MON_{FF}}$ is the probability of a hidden failure in the far field DDM monitoring circuitry.

$$P_{XMTR_{CSE_{DDM}}} = \lambda_{XMTR_{CSE_{DDM}}} \cdot MI$$

$P_{XMTR_{CSE_{DDM}}}$ is the probability that an actual faulty course DDM will be radiated, with no other parameters being affected.

$$P_{FF_{DELAY}} = \frac{P_{INT_{CSE_{DDM}}}}{P_{XMTR_{CSE_{DDM}}} + P_{INT_{CSE_{DDM}}}} \times \frac{P_{INT_{CSE_{DDM}}}}{MI} \cdot 70 \text{ SEC.} \times \lambda_{XMTR_{CSE_{DDM}}} \cdot 70 \text{ SEC.}$$

$P_{FF_{DELAY}}$ is the probability that an actual faulty course DDM will be radiated within the 70-second delay of the far field monitor alarms. If the far field monitor is monitored in the control tower, $P_{FF_{DELAY}} = 0$.

MI = Preventive maintenance interval to check for hidden failures. (One week (168 hours) is assumed).

MM = 2 - If landings are not allowed with monitor mismatch mismatch condition present (ABN light in tower).

MM = 1 - Otherwise.

1. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION DDM SIGNAL DUE TO EQUIPMENT FAILURE. (CONTINUED)

FAILURE RATE DATA

$$\lambda_{MON_{CSE}} = \lambda^*_{35B} = 5.62 \times 10^{-6}$$

$$\lambda_{MON_{FF}} = \lambda_{56C} = 4.422 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda^*_{49F} = \lambda^*_{1E} = 0; \quad \lambda_{1MON} = \lambda^*_{1D2} + \lambda^*_{1S} = 1.140 \times 10^{-6}$$

OTHERWISE:

$$\lambda^*_{49F} = 1.63 \times 10^{-6}$$

$$\lambda^*_{1E} = 1.143 \times 10^{-6}; \quad \lambda_{1MON} = \lambda^*_{1D1} + \lambda^*_{1S} = 1.367 \times 10^{-6}$$

$$\lambda_{XMTR_{CSE_{DDM}}}: \quad \lambda_{3B} = 0.413 \times 10^{-6}$$

$$\lambda_{3F} = 12.832 \times 10^{-6}$$

$$\lambda_{3G} = 1.302 \times 10^{-6}$$

$$\lambda_{12E} = 0.070 \times 10^{-6}$$

$$\lambda_{12F1} = 1.209 \times 10^{-6}$$

$$\lambda_{13} = 0.961 \times 10^{-6}$$

$$\lambda_{68} = 1.347 \times 10^{-6}$$

$$\lambda_{XMTR_{CSE_{DDM}}} = 18.13 \times 10^{-6}$$

1. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION DDM SIGNAL DUE TO EQUIPMENT FAILURE. ((CONTINUED)

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CSE_{DDM}}} = (5.62 \times 10^{-6} \cdot 168\ HR)^2 + (1.140 \times 10^{-6}) \cdot 168\ HR$$
$$= 1.92 \times 10^{-4}$$

$$P_{MON_{FF}} = (4.422 \times 10^{-6} \cdot 168\ HR)^2 = 55.19 \times 10^{-8}$$

$$P_{XMTR_{CSE_{DDM}}} = 18.13 \times 10^{-6} \cdot 168\ HR = 30.46 \times 10^{-4}$$

$$P_{CF} = \frac{(1.92 \times 10^{-4})\ (55.19 \times 10^{-8})}{30.46 \times 10^{-4} + (1.92 \times 10^{-4})\ (55.19 \times 10^{-8})} = 3.48 \times 10^{-8}$$

$$P_{FF_{DELAY}} = \frac{1.92}{30.46 + 1.92} \times \frac{1.92 \times 10^{-4}}{168\ HR} \cdot 70/3600 \cdot (18.13 \times 10^{-6} \times 70/3600)$$
$$= 4.667 \times 10^{-16}$$

$$P_{CSE_{DDM}} = (3.48 \times 10^{-8})(1.92 \times 10^{-4})(55.19 \times 10^{-8})(30.46 \times 10^{-4}) + 4.667 \times 10^{-16}$$
$$= 1.12 \times 10^{-20} + 4.667 \times 10^{-16} = 4.667 \times 10^{-16}$$

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CSE_{DDM}}} = (5.62 \times 10^{-6} \cdot 168\ HR) + (1.367 \times 10^{-6}) \cdot 168\ HR$$
$$= 11.74 \times 10^{-4}$$

$$P_{MON_{FF}} = (4.422 \times 10^{-6} \cdot 168\ HR) + (1.63 \times 10^{-6} + 1.143 \times 10^{-6}) \cdot 168\ HR$$
$$= 12.03 \times 10^{-4}$$

$$P_{XMTR_{CSE_{DDM}}} = 30.46 \times 10^{-4}$$

1. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION DDM SIGNAL DUE TO EQUIPMENT FAILURE. (CONTINUED)

$$P_{CF} = \frac{(11.74 \times 10^{-4})(12.09 \times 10^{-4})}{30.46 \times 10^{-4} + (11.74 \times 10^{-4})(12.09 \times 10^{-4})} = 4.66 \times 10^{-4}$$

$$P_{FF_{DELAY}} = 4.667 \times 10^{-16}$$

$$P_{CSE_{DDM}} = (4.66 \times 10^{-4}) \cdot (11.74 \times 10^{-4}) \cdot (12.09 \times 10^{-4}) \cdot (30.46 \times 10^{-4}) + 4.66 \times 10^{-16}$$

$$P_{CSE_{DDM}} = 2.023 \times 10^{-12}$$

2. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION SDM SIGNAL, I.E., INCORRECT PERCENTAGE MODULATION.

CALCULATION

$$P_{CSE_{SDM}} = P_{CF} \times P_{INT_{SDM/SEN}} \times P_{XMTR_{CSE_{SDM}}}$$

WHERE

$$P_{CF} = \frac{P_{INT_{SDM/SEN}}}{P_{XMTR_{CSE_{SDM}}} + P_{INT_{SDM/SEN}}}$$

P_{CF} is a conditional factor expressing the fact that all monitoring which will detect an SDM fault ($P_{INT_{SDM/SEN}}$) must be lost before transmission of a faulty SDM signal ($P_{XMTR_{CSE_{SDM}}}$) in order for such a signal to be undetected.

$$P_{INT_{SDM/SEN}} = (\lambda_{MON_{CSE}} \cdot MI)^{MM} \cdot (\lambda_{MON_{SEN}} \cdot MI)^{MM} + \lambda_{1MON} \cdot MI$$

$P_{INT_{SDM/SEN}}$ is the probability of a hidden failure in the integral monitoring or control unit such that a faulty course SDM signal would be undetected. This factor expresses the fact that a faulty course SDM signal would cause alarms from both the course SDM integral monitors and the sensitivity integral monitors, which share the same processing in the control unit (λ_{1MON})

$$P_{XMTR_{CSE_{SDM}}} = \lambda_{XMTR_{CSE_{SDM}}} \cdot MI$$

$P_{XMTR_{CSE_{SDM}}}$ is the probability that an actual faulty course SDM signal will be radiated, while no other parameters are affected.

MI = Preventive maintenance interval to check for hidden failures. (One week - 168 hours - is assumed.)

MM =
- 2 - If landings are not allowed with a monitor mismatch condition present (ABN light in tower).
- 1 - Otherwise.

2. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION SDM SIGNAL, I.E., INCORRECT PERCENTAGE MODULATION. (CONTINUED)

FAILURE RATE DATA

$$\lambda_{MON_{CSE}} = \lambda^*_{35B} = \lambda^*_{36B} = 5.62 \times 10^{-6}$$

$$\lambda_{MON_{SEN}} = \lambda^*_{38B} = \lambda^*_{39B} = 3.12 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda_{1MON} = \lambda^*_{1D1} + \lambda^*_{1S} = 1.140 \times 10^{-6}$$

OTHERWISE:

$$\lambda_{1MON} = \lambda^*_{1D1} + \lambda^*_{1S} = 1.367 \times 10^{-6}$$

$$\lambda_{XMTR_{CSE_{SDM}}}: \quad \lambda_{3B} = 0.413 \times 10^{-6}$$

$$\lambda_{3G} = 1.302 \times 10^{-6}$$

$$\lambda_{12D} = 0.070 \times 10^{-6}$$

$$\lambda_{12F1} = 1.209 \times 10^{-6}$$

$$\lambda_{13} = 0.961 \times 10^{-6}$$

$$\lambda_{68} = 1.347 \times 10^{-6}$$

$$\lambda_{XMTR_{CSE_{SDM}}} = 5.30 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{SDM/SEN}} = (5.62 \times 10^{-6} \cdot 168\ HR)^2 + (3.12 \times 10^{-6} \cdot 168\ HR)^2 + (1.140 \times 10^{-6} \cdot 168\ HR)$$
$$= 8.91 \times 10^{-7} + 2.75 \times 10^{-7} + 1.92 \times 10^{-4} = 1.93 \times 10^{-4}$$

$$P_{XMTR_{CSE_{SDM}}} = 5.30 \times 10^{-6} \cdot 168\ HR = 8.90 \times 10^{-4}$$

2. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION SDM SIGNAL, I.E., INCORRECT PERCENTAGE MODULATION. (CONTINUED)

$$P_{CF} = \frac{1.93}{8.90 + 1.93} = 0.178$$

$$P_{CSE_{SDM}} = 0.178 \cdot (1.93 \times 10^{-4}) \cdot (8.90 \times 10^{-4})$$

$$P_{CSE_{SDM}} = 3.082 \times 10^{-8}$$

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{SDM/SEN}} = (5.62 \times 10^{-6} \cdot 168\ HR) + (3.12 \times 10^{-6} \cdot 168\ HR) + (1.367 \times 10^{-6} \cdot 168\ HR)$$

$$= 9.44 \times 10^{-4} + 5.24 \times 10^{-4} + 2.30 \times 10^{-4} = 1.70 \times 10^{-3}$$

$$P_{XMTR_{CSE_{SDM}}} = 8.90 \times 10^{-4}$$

$$P_{CF} = \frac{17.0}{8.90 + 17.0} = 0.657$$

$$P_{CSE_{SDM}} = 0.657 \cdot (1.70 \times 10^{-3}) \cdot (8.90 \times 10^{-4}) = 9.918 \times 10^{-7}$$

3. PROBABILITY OF THE RADIATION OF A SIGNAL THAT IS FAULTY WITH RESPECT TO COURSE RF POWER.

CALCULATION

$$P_{CSE_{RF}} = P_{CF} \times P_{INT_{CSE_{RF}}} \times P_{XMTR_{CSE_{RF}}}$$

WHERE

$$P_{CF} = \frac{P_{INT_{CSE_{RF}}}}{P_{XMTR_{CSE_{RF}}} + P_{INT_{CSE_{RF}}}}$$

P_{CF} is a conditional factor, expressing the fact that RF monitoring must be lost before radiation of a faulty RF signal in order for such a signal to be undetected.

$$P_{INT_{CSE_{RF}}} = (\lambda_{MON_{CSE}} \cdot MI)^{MM} + \lambda_{MON} \cdot MI$$

$P_{INT_{CSE_{RF}}}$ is the probability of failure of course RF integral monitoring circuitry (hidden failure).

$$P_{XMTR_{CSE_{RF}}} = \lambda_{XMTR_{CSE_{RF}}} \cdot MI$$

$P_{XMTR_{CSE_{RF}}}$ is the probability that an actual faulty signal with respect to RF power limit will be radiated, with no other parameter affected.

MI = Maintenance Interval (168 hours assumed)

$$MM = \begin{cases} 2 & \text{- If landings are not allowed with a monitor mismatch condition present (ABN light in tower).} \\ 1 & \text{- Otherwise.} \end{cases}$$

FAILURE RATE DATA

$$\lambda_{MON_{FF}} = \lambda^*_{35B} = 5.62 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda_{1MON} = \lambda^*_{1D2} + \lambda^*_{1S} = 1.140 \times 10^{-6}$$

OTHERWISE:

$$\lambda_{1MON} = \lambda^*_{1D1} + \lambda^*_{1S} = 1.367 \times 10^{-6}$$

3. PROBABILITY OF THE RADIATION OF A SIGNAL THAT IS FAULTY WITH RESPECT TO COURT RF POWER. (CONTINUED)

FAILURE RATE DATA (CONTINUED)

$\lambda_{XMTR_{CSE_{RF}}}$:

$$\lambda_{02B} = 7.150 \times 10^{-6}$$
$$\lambda_{60} = 4.727 \times 10^{-6}$$
$$\lambda_{62} = 9.984 \times 10^{-6}$$
$$\lambda_{3B} = 0.413 \times 10^{-6}$$
$$\lambda_{3G} = 1.302 \times 10^{-6}$$
$$\lambda_{12F1} = 1.209 \times 10^{-6}$$
$$\lambda_{13} = 0.961 \times 10^{-6}$$
$$\lambda_{68} = 1.347 \times 10^{-6}$$
$$\lambda_{XMTR_{CSE_{RF}}} = 27.09 \times 10^{-6}$$

$$P_{XMTR_{CSE_{RF}}} = 27.09 \times 10^{-6} \cdot 168 \text{ HR} = 45.51 \times 10^{-4}$$

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CSE_{RF}}} = (5.62 \times 10^{-6} \cdot 168 \text{ HR})^2 + (1.140 \times 10^{-6} \cdot 168 \text{ HR}) = 1.92 \times 10^{-4}$$

$$P_{CF} = \frac{1.92}{45.51 + 1.92} = 4.048 \times 10^{-2}$$

$$P_{CSE_{RF}} = (4.048 \times 10^{-2})(1.92 \times 10^{-4})(45.51 \times 10^{-4}) = 3.553 \times 10^{-8}$$

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CSE_{RF}}} = (5.62 \times 10^{-6} \cdot 168 \text{ HR}) + (1.367 \times 10^{-6} \cdot 168 \text{ HR}) = 11.74 \times 10^{-4}$$

$$P_{CF} = \frac{11.74}{45.51 + 11.74} = 0.205$$

$$P_{CSE_{RF}} = 0.205 \cdot (11.74 \times 10^{-4}) \cdot (45.51 \times 10^{-4}) = 1.095 \times 10^{-6}$$

4. PROBABILITY OF THE RADIATION OF A SIGNAL THAT IS FAULTY WITH RESPECT TO COURSE WIDTH - SENSITIVITY DDM.

CALCULATION

$$P_{SEN_{DDM}} = P_{CF} \times P_{INT_{SEN}} \times P_{XMTR_{SEN}}$$

WHERE

$$P_{CF} = \frac{P_{INT_{SEN}}}{P_{XMTR_{SEN}} + P_{INT_{SEN}}}$$

P_{CF} is a conditional factor, as previously described.

$$P_{INT_{SEN}} = (\lambda_{MON_{SEN}} \cdot MI)^{MM} + \lambda_{1MON} \cdot MI$$

$P_{INT_{SEN}}$ is the probability of a failure of the sensitivity DDM integral monitoring circuitry (hidden).

$$P_{XMTR_{SEN}} = \lambda_{XMTR_{SEN}} \cdot MI$$

$P_{XMTR_{SEN}}$ is the probability that a signal that is faulty with respect to course width will be radiated, with no other parameter being affected.

MI = MAINTENANCE INTERVAL (168 HOURS ASSUMED)

$$MM = \begin{cases} 2 - & \text{If landings are not allowed with a monitor mismatch condition present (ABN light in tower).} \\ 1 - & \text{Otherwise.} \end{cases}$$

FAILURE RATE DATA

$$\lambda_{MON_{SEN}} = \lambda^*_{38B} = \lambda^*_{39B} = 3.12 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda_{1MON} = 1.140 \times 10^{-6}$$

OTHERWISE:

$$\lambda_{1MON} = 1.367 \times 10^{-6}$$

4. PROBABILITY OF THE RADIATION OF A SIGNAL THAT IS FAULTY WITH RESPECT TO COURSE WIDTH - SENSITIVITY DDM. (CONTINUED)

FAILURE RATE DATA (CONTINUED)

$$\lambda_{XMTR_{SEN}}: \quad \lambda^{*}_{3G1} = 0.5234 \times 10^{-6}$$

$$\lambda^{*}_{12D} = 0.065 \times 10^{-6}$$

$$\lambda^{**}_{13A} = 0.229 \times 10^{-6}$$

$$\lambda_{XMTR_{SEN}} = 0.817 \times 10^{-6}$$

$$P_{XMTR_{SEN}} = 0.817 \times 10^{-6} \cdot 168 \text{ HR} = 1.37 \times 10^{-4}$$

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{SEN}} = (3.12 \times 10^{-6} \cdot 168 \text{ HR})^2 + (1.140 \times 10^{-6} \cdot 168 \text{ HR}) = 1.92 \times 10^{-4}$$

$$P_{CF} = \frac{1.92}{1.37 + 1.92} = 0.583$$

$$P_{SEN_{DDM}} = 0.583 \cdot (1.92 \times 10^{-4})(1.37 \times 10^{-4}) = 1.534 \times 10^{-8}$$

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{SEN}} = (3.12 \times 10^{-6} \cdot 168 \text{ HR}) + (1.367 \times 10^{-6} \cdot 168 \text{ HR}) = 7.54 \times 10^{-4}$$

$$P_{CF} = \frac{7.54}{1.37 + 7.54} = 0.846$$

$$P_{SEN_{DDM}} = 0.846 \cdot (7.54 \times 10^{-4})(1.37 \times 10^{-4}) = 8.753 \times 10^{-8}$$

5. PROBABILITY OF THE RADIATION OF A FAULTY CLEARANCE SIGNAL (DDM, SDM OR RF).

CALCULATION

$$P_{CL} = P_{CF} \times P_{INT_{CL}} \times P_{XMTR_{CL}}$$

WHERE

$$P_{CF} = \frac{P_{INT_{CL}}}{P_{XMTR_{CL}} + P_{INT_{CL}}}$$

P_{CF} is a conditional factor, as previously discussed.

$$P_{INT_{CL}} = (\lambda_{MON_{CL}} \cdot MI)^{MM} + \lambda_{1MON} \cdot MI$$

$P_{INT_{CL}}$ is the probability of a hidden failure of the clearance monitoring circuitry.

$$P_{XMTR_{CL}} = \lambda_{XMTR_{CL}} \cdot MI$$

$P_{XMTR_{CL}}$ is the probability that the radiation of the clearance signal will be faulty with respect to DDM, SDM or RF parameters.

MI = Maintenance interval (168 hours assumed)

$$MM = \begin{cases} 2 - & \text{If landings are not allowed with a monitor mismatch condition present (ABN light in tower).} \\ 1 - & \text{Otherwise.} \end{cases}$$

FAILURE RATE DATA

$$\lambda_{MON_{CL}} = \lambda^*_{43B} = \lambda^*_{44B} = 5.78 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda_{1MON} = 1.140 \times 10^{-6}$$

OTHERWISE:

$$\lambda_{1MON} = 1.367 \times 10^{-6}$$

5. PROBABILITY OF THE RADIATION OF A FAULTY CLEARANCE SIGNAL (DDM, SDM OR RF).

FAILURE RATE DATA (CONTINUED)

$$\lambda_{XMTR_{CL}} : \begin{array}{ll} \lambda_{4A} & = 1.446 \times 10^{-6} \\ \lambda_{4B} & = 7.150 \times 10^{-6} \\ \lambda_{5} & = 10.250 \times 10^{-6} \\ \lambda_{3H} & = 1.552 \times 10^{-6} \\ \lambda_{3I} & = 0.388 \times 10^{-6} \\ \lambda_{3J} & = 0.756 \times 10^{-6} \\ \lambda_{12F1} & = 1.209 \times 10^{-6} \\ \lambda_{12E} & = 0.070 \times 10^{-6} \\ \lambda_{14} & = 0.194 \times 10^{-6} \\ \lambda_{69} & = 0.615 \times 10^{-6} \\ \lambda_{64} & = 2.631 \times 10^{-6} \\ \hline \lambda_{XMTR_{CL}} & = 26.26 \times 10^{-6} \end{array}$$

$$P_{XMTR_{CL}} = 26.26 \times 10^{-6} \cdot 168 \text{ HR} = 44.12 \times 10^{-4}$$

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CL}} = (5.78 \times 10^{-6} \cdot 168 \text{ HR})^2 + (1.140 \times 10^{-6} \cdot 168 \text{ HR}) = 1.92 \times 10^{-4}$$

$$P_{CF} = \frac{1.92}{44.12 + 1.92} = 4.17 \times 10^{-2}$$

$$P_{CL} = (4.17 \times 10^{-2})(1.92 \times 10^{-4})(44.12 \times 10^{-4}) = 3.551 \times 10^{-8}$$

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CL}} = (5.78 \times 10^{-6} \cdot 168 \text{ HR}) + (1.367 \times 10^{-6} \cdot 168 \text{ HR}) = 12.01 \times 10^{-4}$$

$$P_{CF} = \frac{12.01}{44.12 + 12.01} = 0.214$$

$$P_{CL} = 0.214 \cdot (12.01 \times 10^{-4})(44.12 \times 10^{-4}) = 1.133 \times 10^{-6}$$

6. PROBABILITY OF THE RADIATION OF A SIGNAL GIVING A FAULTY COURSE POSITION AT THE FAR FIELD ONLY.

CALCULATION

$$P_{FF_{ONLY}} = P_{CF} \times P_{MON_{FF}} \times P_{FF_{CSE_{DDM}}} + P_{FF_{ONLY_{DELAY}}}$$

WHERE

$$P_{CF} = \frac{P_{MON_{FF}}}{P_{MON_{FF}} + P_{FF_{CSE_{DDM}}}}$$

P_{CF} is a conditional factor, as previously discussed.

$$P_{MON_{FF}} = (\lambda_{MON_{FF}} \cdot MI)^{MM} + (\lambda^*_{49B} + \lambda^*_{1E}) \times MI$$

$P_{MON_{FF}}$ is the probability of a hidden failure in the far field DDM monitoring circuitry.

$P_{FF_{CSE_{DDM}}}$ is unpredictable, being a function of runway activity. ($P_{FF_{CSE_{DDM}}} = 0$ assumed for the base case.)

$P_{FF_{CSE_{DDM}}}$ is the probability that the ILS signal will be faulty with respect to DDM tolerance at the far field due to external runway disturbances during the critical landing phase of a landing (assumed to be 30 seconds for the base case).

$$P_{FF_{ONLY_{DELAY}}} = P_{FF_{CSE_{DDM}}} \cdot \frac{70 \text{ SEC}}{30 \text{ SEC}}$$

$P_{FF_{ONLY_{DELAY}}}$ is the probability that the ILS signal will be faulty with respect to DDM tolerance at the far field due to external disturbances during the 70 second delay of the far field monitor alarm.

FAILURE RATE DATA

$$\lambda_{MON_{FF}} = 4.422 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda^*_{49B} = \lambda^*_{1E} = 0$$

$$P_{MON_{FF}} = (4.422 \times 10^{-6} \cdot 168 \text{ HR})^2 = 5.519 \times 10^{-7}$$

OTHERWISE:

$$\lambda^*_{49B} = 1.63 \times 10^{-6}$$

$$\lambda^*_{1E} = 1.143 \times 10^{-6}$$

$$P_{MON_{FF}} = (4.422 \times 10^{-6} \cdot 168 \text{ HR}) + (1.63 \times 10^{-6} + 1.143 \times 10^{-6}) \cdot 168 = 12.09 \times 10^{-4}$$

$$P_{FF_{ONLY}} = P_{CF} \cdot P_{MON_{FF}} \cdot 0 + 0 \cdot \frac{70 \text{ SEC}}{30 \text{ SEC}} \qquad \text{(BASE CASE)}$$

1. SINGLE FAILURES IN THE LOCALIZER EQUIPMENT THAT CAUSE IMMEDIATE LOCALIZER SHUTDOWN.

CALCULATION

$$P_S = \sum \lambda_{\text{SINGLE FAILURES}} \times T_C$$

$\lambda_{\text{SINGLE FAILURES}}$:

$$\lambda^*_{1A2} = 1.829 \times 10^{-6}$$
$$\lambda^*_{1B} = 2.982 \times 10^{-6}$$
$$\lambda^*_{1M} = 1.039 \times 10^{-6}$$
$$\lambda^*_{1AA} = 0.88 \times 10^{-6}$$
$$\lambda_{12F} = 2.417 \times 10^{-6}$$
$$\lambda_{13} = 0.916 \times 10^{-6}$$
$$\lambda_{66} = 1.116 \times 10^{-6}$$
$$\lambda_{68} = 1.347 \times 10^{-6}$$
$$\lambda_{14} = 0.194 \times 10^{-6}$$
$$\lambda_{67} = 0.311 \times 10^{-6}$$
$$\lambda_{69} = 0.615 \times 10^{-6}$$
$$\lambda_{34F} = 0.137 \times 10^{-6}$$
$$\lambda_{34G} = 0.290 \times 10^{-6}$$
$$\lambda_{34H} = 0.262 \times 10^{-6}$$
$$\lambda^*_{49E} = 1.845 \times 10^{-6}$$
$$\lambda_{49M} = 0.690 \times 10^{-6}$$
$$\lambda_{19A} = 0.100 \times 10^{-6}$$
$$\lambda_{20A} = 0.789 \times 10^{-6}$$
$$\lambda_{20B} = 0.386 \times 10^{-6}$$
$$\lambda_{23A} = 0.789 \times 10^{-6}$$
$$\lambda_{23B} = 0.386 \times 10^{-6}$$
$$\lambda_{26A} = 0.789 \times 10^{-6}$$
$$\lambda_{26B} = 0.386 \times 10^{-6}$$

$$\sum \lambda = 20.537 \times 10^{-6}$$

T_C = Critical Landing Time Interval

FOR A CRITICAL INTERVAL OF 30 SECONDS:

$$P_S = 20.537 \times 10^{-6} \cdot 30 \text{ SEC} = (20.537 \times 10^{-6}) \cdot 30/_{3600} \text{ HR}^{-6}$$
$$P_S = 1.711 \times 10^{-7}$$

2. FAILURE IN THE MAIN TRANSMITTING UNIT AND A FAILURE IN THE STANDBY TRANSMITTING UNIT. BOTH FAILURES OCCUR WITHIN THE CRITICAL PHASE OF THE LANDING, AND IT IS IMMATERIAL WHICH FAILURE OCCURS FIRST.

CALCULATION

$$P_{AB} = P_{A+T} \times P_B$$

WHERE

P_{A+T} is the probability of loss of the main transmitting unit or spontaneous transfer due to single failures in the control unit.

P_B is the probability of loss of the standby transmitting unit.

$$P_{AB} = \left[(\lambda_A + \lambda^*_{1A1}) \cdot T_C \right] \cdot (\lambda_B \cdot T_C)$$

$$\lambda^*_{1A1} = 3.18 \times 10^{-6}$$

$\lambda_{2A} = 1.446 \times 10^{-6}$	$\lambda_{7A} = 1.446 \times 10^{-6}$
$\lambda_{60} = 4.727 \times 10^{-6}$	$\lambda_{61} = 4.727 \times 10^{-6}$
$\lambda_{62} = 9.984 \times 10^{-6}$	$\lambda_{63} = 9.984 \times 10^{-6}$
$\lambda_{2B} = 7.150 \times 10^{-6}$	$\lambda_{7B} = 7.150 \times 10^{-6}$
$\lambda_{4A} = 1.446 \times 10^{-6}$	$\lambda_{9A} = 1.446 \times 10^{-6}$
$\lambda_{4B} = 7.150 \times 10^{-6}$	$\lambda_{9B} = 7.150 \times 10^{-6}$
$\lambda_{5} = 10.250 \times 10^{-6}$	$\lambda_{10} = 10.250 \times 10^{-6}$
$\lambda_{64} = 2.631 \times 10^{-6}$	$\lambda_{65} = 2.631 \times 10^{-6}$
$\lambda_{3A} = 2.413 \times 10^{-6}$	$\lambda_{8A} = 2.413 \times 10^{-6}$
$\lambda_{3B} = 0.413 \times 10^{-6}$	$\lambda_{8B} = 0.413 \times 10^{-6}$
$\lambda_{3C} = 1.453 \times 10^{-6}$	$\lambda_{8C} = 1.453 \times 10^{-6}$
$\lambda_{3F} = 12.832 \times 10^{-6}$	$\lambda_{8F} = 12.832 \times 10^{-6}$
$\lambda_{3G} = 1.302 \times 10^{-6}$	$\lambda_{8G} = 1.302 \times 10^{-6}$
$\lambda_{3H} = 1.552 \times 10^{-6}$	$\lambda_{8H} = 1.552 \times 10^{-6}$
$\lambda_{3I} = 0.388 \times 10^{-6}$	$\lambda_{8I} = 0.388 \times 10^{-6}$

(CONTINUED) (CONTINUED)

2. FAILURE IN THE MAIN TRANSMITTING UNIT AND A FAILURE IN THE STANDBY TRANSMITTING UNIT. BOTH FAILURES OCCUR WITHIN THE CRITICAL PHASE OF THE LANDING, AND IT IS IMMATERIAL WHICH FAILURE OCCURS FIRST.

CALCULATION (CONTINUED)

$$\lambda_{3J} = 0.756 \times 10^{-6}$$
$$\lambda_{6A} = 3.949 \times 10^{-6}$$
$$\lambda_{6B} = 13.134 \times 10^{-6}$$
$$\lambda_{12B} = 0.134 \times 10^{-6}$$
$$\lambda_{12D} = 0.070 \times 10^{-6}$$
$$\lambda_{12E} = 0.070 \times 10^{-6}$$
$$\lambda_{A} = 83.250 \times 10^{-6}$$

$$\lambda_{8J} = 0.756 \times 10^{-6}$$
$$\lambda_{11A} = 3.949 \times 10^{-6}$$
$$\lambda_{11B} = 13.134 \times 10^{-6}$$
$$\lambda_{12B} = 0.134 \times 10^{-6}$$
$$\lambda_{B} = 83.110 \times 10^{-6}$$

$$P_{AB} = (86.430 \times 10^{-6} \cdot 30 \text{ SEC}) \cdot (83.110 \times 10^{-6} \cdot 30 \text{ SEC})$$

$$P_{AB} = 4.988 \times 10^{-13}$$

3. A HIDDEN FAILURE IN THE EQUIPMENT WHICH ESSENTIALLY INHIBITS THE TRANSFER CAPABILITY OF THE TRANSMITTING UNITS AND THEN A FAILURE IN THE MAIN TRANSMITTING UNIT.

CALCULATION

$$P_{AC} = \frac{\lambda_C}{\lambda_A + \lambda_C} X (P_A X P_C)$$

WHERE

P_A is the probability of the loss of the main transmitting unit.

P_C is the probability of the loss of the transfer to standby capability.

$\frac{\lambda_C}{\lambda_A + \lambda_C}$ is the conditional probability that the hidden failures modes (λ_C) will occur prior to a main transmitting unit failure that initiates a transfer (λ_A).

$$P_A = \lambda_A \cdot T_C = (83.25 X 10^{-6}) \cdot 30 \text{ SEC} = 6.94 X 10^{-7}$$

$$P_C = \lambda_C \cdot MI = \lambda_C \cdot 168 \text{ HR}$$

$$\lambda_C = \lambda^*_{1D3} + \lambda_{1T} + \lambda_{12A}$$

$$\lambda^*_{1D3} = 1.730 X 10^{-6}$$

$$\lambda_{1T} = 0.545 X 10^{-6}$$

$$\lambda_{12A} = 0.22 X 10^{-6}$$

$$\lambda_C = 2.49 X 10^{-6}$$

$$P_C = (2.49 X 10^{-6}) \cdot 168 = 4.192 X 10^{-4}$$

$$P_{AC} = \frac{.765}{2.49 + 83.25} \cdot (4.192 X 10^{-4}) \cdot (6.94 X 10^{-7}) = 8.461 X 10^{-12}$$

4. A FAILURE THAT WILL RESULT IN THE GENERATION OF A FAULTY COURSE DDM, SDM, OR RF PARAMETER FROM THE STANDBY TRANSMITTING UNIT, FOLLOWED BY ANY FAILURE IN THE MAIN TRANSMITTER OR CONTROL UNIT WHICH CAN INITIATE A TRANSFER.

CALCULATION

$$P_{STBY_{CSE}} = \frac{\lambda_{B_{CSE}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{CSE}}} \times P_{B_{CSE}} \times P_{A+T}$$

WHERE

$P_{B_{CSE}}$ is the probability of a failure that will result in the generation of a faulty course DDM, SDM, or RF parameter from the standby transmitter.

P_{A+T} is the probability of loss of the main transmitting unit or spontaneous transfer due to single failures in the control unit (previously identified).

$\frac{\lambda_{B_{CSE}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{CSE}}}$ is the conditional probability that the standby transmitter failure modes ($\lambda_{B_{CSE}}$) will occur prior to a transmitter or control unit failure that initiates a transfer ($\lambda_A + \lambda^*_{1A1}$).

$\lambda_{B_{CSE}}$:

$$\begin{aligned}
\lambda_{7B} &= 7.150 \times 10^{-6} \\
\lambda_{61} &= 4.727 \times 10^{-6} \\
\lambda_{63} &= 9.984 \times 10^{-6} \\
\lambda_{8B} &= 0.413 \times 10^{-6} \\
\lambda_{8F} &= 12.832 \times 10^{-6} \\
\lambda_{8G} &= 1.302 \times 10^{-6} \\
\hline
\lambda_{B_{CSE}} &= 36.41 \times 10^{-6}
\end{aligned}$$

$$\lambda_A + \lambda^*_{1A1} = 83.25 \times 10^{-6} + 3.18 \times 10^{-6} = 86.43 \times 10^{-6}$$

$$P_{B_{CSE}} = \lambda_{B_{CSE}} \cdot 168 \text{ HR} = 61.16 \times 10^{-4}$$

$$P_{A+T} = (\lambda_A + \lambda^*_{1A1}) \cdot 30 \text{ SEC} = 0.720 \times 10^{-6}$$

$$P_{STBY_{CSE}} = \frac{36.41}{86.43 + 36.41} \cdot (61.16 \times 10^{-4}) \cdot (0.720 \times 10^{-6}) = 1.305 \times 10^{-9}$$

5. A FAILURE THAT WILL RESULT IN THE GENERATION OF A FAULTY COURSE WIDTH (DDM) PARAMETER FROM THE STANDBY TRANSMITTING UNIT, FOLLOWED BY ANY FAILURE IN THE MAIN TRANSMITTER OR CONTROL UNIT WHICH CAN INITIATE A TRANSFER.

CALCULATION

$$P_{STBY_{SEN}} = \left(\frac{\lambda_{B_{SEN}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{SEN}}} \right) X\ P_{B_{SEN}}\ X\ P_{A+T}$$

WHERE

$P_{B_{SEN}}$ is the probability of a failure that will result in the generation of a faulty course width (DDM) parameter from the standby transmitter.

P_{A+T} - previously identified

$\left(\frac{\lambda_{B_{SEN}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{SEN}}} \right)$ is a conditional probability factor, as previously discussed

$$\lambda_{B_{SEN}} = \lambda_{8B} + \lambda_{8F} + \lambda_{8G}$$

$$= 0.413 \times 10^{-6} + 12.832 \times 10^{-6} + 1.302 \times 10^{-6} = 14.55 \times 10^{-6}$$

$$\lambda_A + \lambda^*_{1A1} = 86.43 \times 10^{-6}$$

$$P_{B_{SEN}} = \lambda_{B_{SEN}} \cdot 168\ HR = 24.44 \times 10^{-4}$$

$$P_{A+T} = (\lambda_A + \lambda^*_{1A1}) \cdot .30\ SEC = 0.720 \times 10^{-6}$$

$$P_{STBY_{SEN}} = \frac{14.55}{86.43 + 14.55} \cdot (24.44 \times 10^{-4}) \cdot (0.720 \times 10^{-6}) = 2.536 \times 10^{-10}$$

6. A FAILURE THAT WILL RESULT IN THE GENERATION OF A FAULTY CLEARANCE DDM, SDM OR RF PARAMETER FROM THE STANDBY TRANSMITTING UNIT, FOLLOWED BY ANY FAILURE IN THE MAIN TRANSMITTER OR CONTROL UNIT WHICH CAN INITIATE A TRANSFER.

CALCULATION

$$P_{STBY_{CL}} = \left(\frac{\lambda_{B_{CL}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{CL}}} \right) \cdot P_{B_{CL}} \cdot P_{A+T}$$

WHERE

$P_{B_{CL}}$ is the probability of a failure that will result in the generation of a faulty clearance DDM, SDM or RF parameter from the standby transmitter.

P_{A+T} - previously identified

$\left(\frac{\lambda_{B_{CL}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{CL}}} \right)$ is a conditional probability factor, as previously discussed.

$\lambda_{B_{CL}}$:

$$\lambda_{9A} = 1.446 \times 10^{-6}$$
$$\lambda_{9B} = 7.150 \times 10^{-6}$$
$$\lambda_{10} = 10.250 \times 10^{-6}$$
$$\lambda_{65} = 2.631 \times 10^{-6}$$
$$\lambda_{8H} = 1.552 \times 10^{-6}$$
$$\lambda_{8I} = 0.388 \times 10^{-6}$$
$$\lambda_{8J} = 0.756 \times 10^{-6}$$
$$\lambda_{B_{CL}} = 24.17 \times 10^{-6}$$

$$\lambda_A + \lambda^*_{1A1} = 86.43 \times 10^{-6}$$

$$P_{B_{CL}} = \lambda_{B_{CL}} \cdot 168 \text{ HR} = 40.61 \times 10^{-6}$$

$$P_{A+T} = (\lambda_A + \lambda^*_{1A1}) \cdot 30 \text{ SEC} = 0.720 \times 10^{-6}$$

$$P_{STBY_{CL}} = \frac{24.17}{86.43 + 24.17} (40.61 \times 10^{-6})(0.720 \times 10^{-6}) = 6.391 \times 10^{-10}$$

7. A FAILURE THAT WILL RESULT IN THE GENERATION OF A FAULTY I.D. SIGNAL (OR LOSS) OF THE STANDBY TRANSMITTING UNIT, FOLLOWED BY ANY FAILURE IN THE MAIN TRANSMITTER OR CONTROL UNIT WHICH CAN INITIATE A TRANSFER.

CALCULATION

$$P_{STBY_{ID}} = \left(\frac{\lambda_{B_{ID}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{ID}}} \right) X P_{B_{ID}} \; X P_{A+T}$$

WHERE

$P_{B_{ID}}$ is the probability of a failure that will result in the generation of a faulty I.D. signal (or loss) of the standby transmitter

P_{A+T} - previously discussed

$\left(\frac{\lambda_{B_{ID}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{ID}}} \right)$ is a conditional probability factor, as previously discussed.

$$\lambda_{B_{ID}}: \quad \begin{aligned} \lambda_{7A} &= 1.446 \times 10^{-6} \\ \lambda_{61} &= 4.727 \times 10^{-6} \\ \lambda_{63} &= 9.984 \times 10^{-6} \\ \lambda_{11A} &= 3.949 \times 10^{-6} \\ \lambda_{11B} &= 13.134 \times 10^{-6} \\ \lambda_{1BB2} &= 0.338 \times 10^{-6} \\ \hline \lambda_{B_{ID}} &= 33.58 \times 10^{-6} \end{aligned}$$

$$\lambda_A + \lambda^*_{1A1} = 8.643 \times 10^{-6}$$

$$P_{B_{ID}} = \lambda_{B_{ID}} \cdot 168 \text{ HR} = 56.41 \times 10^{-4}$$

$$P_{A+T} = (\lambda_A + \lambda^*_{1A1}) \cdot 30 \text{ SEC} = 0.720 \times 10^{-6}$$

$$P_{STBY_{ID}} = \frac{33.58}{86.43 + 33.58} (56.41 \times 10^{-4})(0.720 \times 10^{-6}) = 1.136 \times 10^{-9}$$

8. A FAILURE THAT WILL RESULT IN THE GENERATION OF ANY FAULTY PARAMETER OF THE STANDBY TRANSMITTING UNIT, FOLLOWED BY ANY FAILURE IN THE MAIN TRANSMITTER OR CONTROL UNIT WHICH CAN INITIATE A TRANSFER.

CALCULATION

$$P_{STBY} = \left(\frac{\lambda_B}{\lambda_A + \lambda^*_{1A1} + \lambda_B}\right) X \, (\lambda_B \cdot 168) \, X \, P_{A+T}$$

WHERE

P_{A+T} - previously identified

$\frac{\lambda_B}{\lambda_A + \lambda_{1A1} + \lambda_B}$ is a conditional probability factor, as previously discussed.

$$\lambda_B = 83.110 \, X \, 10^{-6}$$

$$\lambda_A + \lambda^*_{1A1} = 86.43 \, X \, 10^{-6}$$

$$\lambda_B \cdot 168 \text{ HR} = 139.62 \, X \, 10^{-4}$$

$$P_{A+T} = (\lambda_A + \lambda^*_{1A1}) \cdot 30 \text{ SEC} = 0.720 \, X \, 10^{-6}$$

$$P_{STBY} = \frac{83.110}{86.43 + 83.110} \cdot (139.62 \, X \, 10^{-4}) \cdot (0.720 \, X \, 10^{-6}) = 5.071 \, X \, 10^{-9}$$

9. POWER SUPPLY/CONVERTER FAILURES LEADING TO A SHUTDOWN.

CALCULATION

$$P_{PS/CONV} = P_{CONV_{MAIN}} + P_{CONV_{FF}} + P_{PS_{FF}}$$

WHERE

$P_{CONV_{MAIN}}$ is the probability of both main converters failing.

$P_{CONV_{FF}}$ is the probability of both far field monitor converters failing.

$P_{PS_{FF}}$ is the probability of the main power of the far field monitor failing.

$$P_{CONV_{MAIN}} = (\lambda_{17} \times 720\ HR^{1} \cdot (\lambda_{18} \times 30\ SEC)$$

$$P_{CONV_{FF}} = (\lambda_{51A} \times 720\ HR) \cdot (\lambda_{52A} \times 30\ SEC)$$

$$P_{PS_{FF}} = (\lambda_{50B} + \lambda_{BATT_{FF}}) \times 720\ HR^{1} \cdot (\lambda_{50A} \times 30\ SEC)$$

$$\lambda_{17} = \lambda_{18} = 6.598 \times 10^{-6}$$

$$\lambda_{51A} = \lambda_{52A} = 2.412 \times 10^{-6}$$

$$\lambda_{50A} = 5.790 \times 10^{-6}$$

$$\lambda_{50B} = 0.519 \times 10^{-6}$$

$$\lambda_{BATT_{FF}} = 8.0 \times 10^{-6} \quad \text{(Assumed)}$$

$$P_{PS/CONV} = 2.61 \times 10^{-10} + 3.49 \times 10^{-11} + 2.96 \times 10^{-10} = 5.920 \times 10^{-10}$$

[1]A monthly preventive maintenance cycle is assumed for power supply systems.

10. BOTH COURSE /ID MONITORS FAILING, PRODUCING AN ALARM.

CALCULATION

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT;

$$P_{CSE/ID} = (\lambda_{CSE/ID} \cdot T_C)^2 \qquad \text{(CASE 1)}$$

OTHERWISE:

$$P_{CSE/ID} = (\lambda_{CSE/ID} \cdot 168\ HR)\ (\lambda_{CSE/ID} \cdot T_C) \qquad \text{(CASE 2)}$$

$$\lambda_{CSE/ID} = \lambda_{CSE/ID_1} = \lambda_{CSE/ID_2}$$

$$\lambda_{CSE/ID_1}: \quad \lambda^*_{35A} = 13.539 \times 10^{-6}$$

$$\lambda_{34A1} = 1.914 \times 10^{-6}$$

$$\lambda_{CSE/ID_1} = 15.45 \times 10^{-6}$$

$$P_{CSE/ID} = (15.45 \times 10^{-6} \cdot 30\ SEC)^2 = 1.657 \times 10^{-14} \qquad \text{(CASE 1)}$$

$$P_{CSE/ID} = (15.45 \times 10^{-6} \cdot 168\ HR)\ (15.45 \times 10^{-6} \cdot 30\ SEC) = 3.341 \times 10^{-10} \qquad \text{(CASE 2)}$$

11. BOTH SENSITIVITY MONITORS FAILING, PRODUCING AN ALARM.

CALCULATION

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{SEN} = (\lambda_{SEN} \cdot T_C)^2 \qquad \text{(CASE 1)}$$

OTHERWISE:

$$P_{SEN} = (\lambda_{SEN} \cdot 168\ HR)(\lambda_{SEN} \cdot T_C) \qquad \text{(CASE 2)}$$

$$\lambda_{SEN} = \lambda_{SEN_1} = \lambda_{SEN_2}$$

$$\lambda_{SEN_1} = \lambda^*_{38A} = 9.596 \times 10^{-6}$$

$$P_{SEN} = (9.596 \times 10^{-6} \cdot 30\ SEC)^2 = 6.394 \times 10^{-15} \qquad \text{(CASE 1)}$$

$$P_{SEN} = (9.596 \times 10^{-6} \cdot 168\ HR)(9.596 \times 10^{-6} \cdot 30\ SEC) = 1.289 \times 10^{-10} \qquad \text{(CASE 2)}$$

12. BOTH CLEARANCE MONITORS FAILING, PRODUCING AN ALARM.

CALCULATION

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{CL} = (\lambda_{CL} \cdot T_C)^2 \qquad \text{(CASE 1)}$$

OTHERWISE:

$$P_{CL} = (\lambda_{CL} \cdot 168\ \text{HR})(\lambda_{CL} \cdot T_C) \qquad \text{(CASE 2)}$$

$$\lambda_{CL} = \lambda_{CL_1} = \lambda_{CL_2}$$

$$\lambda_{CL_1} = \lambda^*_{43A} = 14.509 \times 10^{-6}$$

$$P_{CL} = (14.509 \times 10^{-6} \cdot 30\ \text{SEC})^2 = 1.461 \times 10^{-14} \qquad \text{(CASE 1)}$$

$$P_{CL} = (14.509 \times 10^{-6} \cdot 168\ \text{HR})\ (14.509 \times 10^{-6} \cdot 30\ \text{SEC}) = 2.947 \times 10^{-10} \qquad \text{(CASE 2)}$$

13. BOTH FAR FIELD MONITORS/RECEIVERS FAILING, PRODUCING AN ALARM.

CALCULATION

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{FF} = (\lambda_{FF} \cdot T_C)^2 \qquad \text{(CASE 1)}$$

OTHERWISE:

$$P_{FF} = (\lambda_{FF} \cdot 168\ \text{HR})\ (\lambda_{FF} \cdot T_C) \qquad \text{(CASE 2)}$$

$$\lambda_{FF} = \lambda_{FF1} = \lambda_{FF2}$$

λ_{FF1}:

$$\lambda_{56B} = 11.099 \times 10^{-6}$$

$$\lambda_{53} = 6.879 \times 10^{-6}$$

$$\lambda_{49H} = 0.022 \times 10^{-6}$$

$$\lambda_{FF1} = 18.00 \times 10^{-6}$$

$$P_{FF} = (18.00 \times 10^{-6} \cdot 30\ \text{SEC})^2 = 2.250 \times 10^{-14} \qquad \text{(CASE 1)}$$

$$P_{FF} = (18.00 \times 10^{-6} \cdot 168\ \text{HR}) \cdot (18.00 \times 10^{-6} \cdot 30\ \text{SEC}) = 4.536 \times 10^{-10} \qquad \text{(CASE 2)}$$

APPENDIX D

GLIDESLOPE FAULTY SIGNAL AND SHUTDOWN PROBABILITY CALCULATIONS

1. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION (PATH ANGLE) DDM SIGNAL.

CALCULATION

$$P_{CSE_{DDM}} = P_{CF} \times P_{INT_{CSE_{DDM}}} \times P_{MON_{NF}} \times P_{XMTR_{CSE_{DDM}}}$$

WHERE

$$P_{CF} = \frac{P_{MON_{NF}} \bullet P_{INT_{CSE_{DDM}}}}{P_{XMTR_{CSE_{DDM}}} + (P_{MON_{NF}} \bullet P_{INT_{CSE_{DDM}}})}$$

P_{CF} is a conditional factor, expressing the fact that all DDM monitoring must be lost before radiation of a faulty DDM signal in order for such a signal to be undetected.

$$P_{INT_{CSE_{DDM}}} = (\lambda_{MON_{CSE}} \bullet MI)^{MM} + \lambda_{1MON} \bullet MI$$

$P_{INT_{CSE_{DDM}}}$ is the probability of failure in the course DDM integral monitoring circuitry.

$$P_{MON_{NF}} = \left[(\lambda_{MON_{NF}} + \lambda_{1X}^{**}) \bullet MI\right]^{MM} + (\lambda_{1E}^{*} \bullet MI)$$

$P_{MON_{NF}}$ is the probability of a hidden failure in the near field DDM monitoring circuitry.

$$P_{XMTR_{CSE_{DDM}}} = \lambda_{XMTR_{CSE_{DDM}}} \bullet MI$$

$P_{XMTR_{CSE_{DDM}}}$ is the probability that an actual faulty course DDM will be radiated, while no other parameters are affected.

MI = Preventive maintenance interval to check for hidden failures. (One week - 168 hours - is assumed.)

$$MM = \begin{cases} 2 - & \text{If landings are not allowed with a monitor mismatch condition present (ABN light in tower).} \\ 1 - & \text{Otherwise.} \end{cases}$$

1. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION (PATH ANGLE) DDM SIGNAL. (CONTINUED)

FAILURE RATE DATA

$$\lambda_{MON_{CSE}} = \lambda^*_{34B} = \lambda^*_{35B} = 5.065 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda_{1MON} = \lambda^*_{1D2} + \lambda^*_{1S} = 1.140 \times 10^{-6}$$

OTHERWISE:

$$\lambda_{1MON} = \lambda^*_{1D1} + \lambda^*_{1S} = 1.367 \times 10^{-6}$$

$$\lambda_{MON_{NF}} = \lambda_{43B} = \lambda_{44B} = 3.822 \times 10^{-6}$$

$$\lambda^{**}_{1X} = 0.262 \times 10^{-6}$$

$$\lambda^*_{1E} = 1.143 \times 10^{-6}$$

$$\lambda_{XMTR_{CSE_{DDM}}}: \quad \lambda_{3B} = 0.427 \times 10^{-6}$$

$$\lambda_{3F} = 12.832 \times 10^{-6}$$

$$\lambda_{3G} = 1.302 \times 10^{-6}$$

$$\lambda_{10D} = 0.070 \times 10^{-6}$$

$$\lambda_{10E1} = 0.466 \times 10^{-6}$$

$$\lambda_{11} = 1.231 \times 10^{-6}$$

$$\lambda_{XMTR_{CSE_{DDM}}} = 16.33 \times 10^{-6}$$

1. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION (PATH ANGLE) DDM SIGNAL (CONTINUED)

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CSE_{DDM}}} = (5.065 \times 10^{-6} \cdot 168\ HR)^2 + (1.140 \times 10^{-6} \cdot 168\ HR)$$
$$= 7.24 \times 10^{-7} + 1.915 \times 10^{-4} = 1.92 \times 10^{-4}$$

$$P_{MON_{NF}} = \left[(3.822 \times 10^{-6} + 0.262 \times 10^{-6}) \cdot 168\ HR\right]^2 + (1.143 \times 10^{-6} \cdot 168\ HR)$$
$$= 4.71 \times 10^{-7} + 1.92 \times 10^{-4} = 1.92 \times 10^{-4}$$

$$P_{XMTR_{CSE_{DDM}}} = 16.33 \times 10^{-6} \cdot 168\ HR = 27.43 \times 10^{-4}$$

$$P_{CF} = \frac{(1.92 \times 10^{-4})^2}{27.43 \times 10^{-4} + (1.92 \times 10^{-4})^2} = 1.34 \times 10^{-5}$$

$$P_{CSE_{DDM}} = (1.34 \times 10^{-5}) \cdot (1.92 \times 10^{-4}) \cdot (1.92 \times 10^{-4}) \cdot (27.43 \times 10^{-4})$$
$$P_{CSE_{DDM}} = 1.370 \times 10^{-15}$$

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CSE_{DDM}}} = (5.065 \times 10^{-6} \cdot 168\ HR) + (1.367 \times 10^{-6} \cdot 168\ HR)$$
$$= 8.51 \times 10^{-4} + 2.296 \times 10^{-4} = 1.08 \times 10^{-3}$$

$$P_{MON_{NF}} = (4.084 \times 10^{-6} \cdot 168\ HR) + (1.143 \times 10^{-6} \cdot 168\ HR) = 8.78 \times 10^{-4}$$

$$P_{XMTR_{CSE_{DDM}}} = 27.43 \times 10^{-4}$$

$$P_{CF} = \frac{(1.08 \times 10^{-3}) \cdot (8.78 \times 10^{-4})}{27.34 \times 10^{-4} + \left[(1.08 \times 10^{-3}) \cdot (8.78 \times 10^{-4})\right]} = 3.46 \times 10^{-4}$$

$$P_{CSE_{DDM}} = (3.46 \times 10^{-4}) \cdot (1.08 \times 10^{-3}) \cdot (8.78 \times 10^{-4}) \cdot (27.43 \times 10^{-4})$$

$$P_{CSE_{DDM}} = 9.001 \times 10^{-13}$$

2. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION SDM SIGNAL, I.E., INCORRECT PERCENTAGE MODULATION.

CALCULATION

$$P_{CSE_{SDM}} = P_{CF} \times P_{INT_{SDM/SEN}} \times P_{XMTR_{CSE_{SDM}}}$$

WHERE

$$P_{CF} = \frac{P_{INT_{SDM/SEN}}}{P_{XMTR_{CSE_{SDM}}} + P_{INT_{SDM/SEN}}}$$

P_{CF} is a conditional factor expressing the fact that all monitoring which will detect an SDM fault ($P_{INT_{SDM/SEN}}$) must be lost before transmission of a faulty SDM signal ($P_{XMTR_{CSE_{SDM}}}$) can go undetected.

$$P_{INT_{SDM/SEN}} = (\lambda_{MON_{CSE}} \cdot MI)^{MM} \cdot (\lambda_{MON_{SEN}} \cdot MI)^{MM} + \lambda_{1MON} \cdot MI$$

$P_{INT_{SDM/SEN}}$ is the probability of a hidden failure in the integral monitoring or control unit such that a faulty course SDM signal would be undetected. This factor expresses the fact that a faulty course SDM signal would cause alarms from both the course SDM integral monitors and the sensitivity integral monitors, which share the same processing in the control unit ($\lambda_{1MON} \cdot MI$).

$$P_{XMTR_{CSE_{SDM}}} = \lambda_{XMTR_{CSE_{SDM}}} \cdot MI$$

$P_{XMTR_{CSE_{SDM}}}$ is the probability that an actual faulty course SDM signal will be radiated, while no other parameters are affected.

MI = Preventive maintenance interval to check for hidden failures. (One week - 168 hours - is assumed.)

$$MM = \begin{cases} 2 & \text{- If landings are not allowed with a monitor mismatch condition present (ABN light in tower).} \\ 1 & \text{- Otherwise.} \end{cases}$$

2. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION SDM SIGNAL, I.E., INCORRECT PERCENTAGE MODULATION. (CONTINUED)

FAILURE RATE DATA

$$\lambda_{MON_{CSE}} = \lambda^*_{34B} = \lambda^*_{35B} = 5.065 \times 10^{-6}$$

$$\lambda_{MON_{SEN}} = \lambda^*_{37B} = \lambda^*_{38B} = 3.121 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda_{1MON} = \lambda^*_{1D2} + \lambda^*_{1S} = 1.140 \times 10^{-6}$$

OTHERWISE:

$$\lambda_{1MON} = \lambda^*_{1D1} + \lambda^*_{1S} = 1.357 \times 10^{-6}$$

$$\lambda_{XMTR_{CSE_{SDM}}}: \quad \begin{aligned} \lambda_{3B} &= 0.427 \times 10^{-6} \\ \lambda_{3G} &= 1.302 \times 10^{-6} \\ \lambda_{10D} &= 0.070 \times 10^{-6} \\ 2\lambda_{10E1} &= 0.932 \times 10^{-6} \\ \lambda_{11} &= 1.231 \times 10^{-6} \\ \hline \lambda_{XMTR_{CSE_{SDM}}} &= 3.96 \times 10^{-6} \end{aligned}$$

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{SDM/SEN}} = (5.065 \times 10^{-6} \cdot 168)^2 + (3.121 \times 10^{-6} \cdot 168)^2 + (1.140 \times 10^{-6} \cdot 168)$$
$$= 7.24 \times 10^{-7} + 2.75 \times 10^{-7} + 1.92 \times 10^{-4} = 1.93 \times 10^{-4}$$

$$P_{XMTR_{CSE_{SDM}}} = 3.96 \times 10^{-6} \cdot 168 = 6.65 \times 10^{-4}$$

$$P_{CF} = \frac{1.93}{6.65 + 1.93} = 0.225$$

$$P_{CSE_{SDM}} = 0.225 \cdot (1.93 \times 10^{-4}) \cdot (6.65 \times 10^{-4}) = 2.899 \times 10^{-8}$$

2. PROBABILITY OF THE RADIATION OF A FAULTY COURSE POSITION SDM SIGNAL, I.E., INCORRECT PERCENTAGE MODULATION. (CONTINUED)

FAILURE RATE DATA (CONTINUED)

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{SDM/SEN}} = (5.065 \times 10^{-6} \cdot 168) + (3.121 \times 10^{-6} \cdot 168) + (1.367 \times 10^{-6} \cdot 168)$$
$$= 8.51 \times 10^{-4} + 5.24 \times 10^{-4} + 1.92 \times 10^{-4} = 1.57 \times 10^{-3}$$

$$P_{XMTR_{CSE_{SDM}}} = 6.65 \times 10^{-4}$$

$$P_{CF} = \frac{15.7}{6.65 + 15.7} = 0.702$$

$$P_{CSE_{SDM}} = 0.702 \cdot (1.57 \times 10^{-3})(6.65 \times 10^{-4}) = 7.548 \times 10^{-7}$$

3. PROBABILITY OF THE RADIATION OF A SIGNAL THAT IS FAULTY WITH RESPECT TO COURSE RF POWER.

CALCULATION

$$P_{CSE_{RF}} = P_{CF} \times P_{INT_{CSE_{RF}}} \times P_{NF_{RF}} \times P_{XMTR_{CSE_{RF}}}$$

WHERE

$$P_{CF} = \frac{P_{INT_{CSE_{RF}}} \bullet P_{NF_{RF}}}{P_{XMTR_{CSE_{RF}}} + (P_{INT_{CSE_{RF}}} \bullet P_{NF_{RF}})}$$

P_{CF} is a conditional factor, expressing the fact that all RF monitoring must be lost before radiation of a faulty RF signal in order for such a signal to be undetected.

$$P_{INT_{CSE_{RF}}} = (\lambda_{MON_{CSE}} \bullet MI)^{MM} + \lambda_{1MON} \bullet MI$$

$P_{INT_{CSE_{RF}}}$ is the probability of failure in the course RF integral monitoring circuitry.

$$P_{NF_{RF}} = (\lambda_{MON_{NF}} + \lambda_{1X}^{**} + \lambda_{1Y}^{**}) \bullet MI$$

$P_{NF_{RF}}$ is the probability that the near field monitoring circuitry will fail to generate an "abnormal" indication when a faulty RF signal is radiated.

$$P_{XMTR_{CSE_{RF}}} = \lambda_{XMTR_{CSE_{RF}}} \bullet MI$$

$P_{XMTR_{CSE_{RF}}}$ is the probability that a signal that is faulty with respect to RF power will be radiated while no other parameters are affected.

MI = Preventive maintenance interval to check for hidden failures. (one week - 168 hours - is assumed.)

$$MM = \begin{cases} 2 & \text{- If landings are not allowed with a monitor mismatch condition present (ABN light in tower).} \\ 1 & \text{- Otherwise.} \end{cases}$$

3. PROBABILITY OF THE RADIATION OF A SIGNAL THAT IS FAULTY WITH RESPECT TO COURSE RF POWER. (CONTINUED)

FAILURE RATE DATA

$$\lambda_{MON_{CSE}} = \lambda^{*}_{34B} = \lambda^{*}_{35B} = 5.065 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda_{1MON} = 1.140 \times 10^{-6}$$

OTHERWISE:

$$\lambda_{1MON} = 1.367 \times 10^{-6}$$

$$\lambda_{MON_{NF}} = \lambda_{43B} = \lambda_{44B} = 3.822 \times 10^{-6}$$

$$\lambda^{**}_{1X} = 0.262 \times 10^{-6}$$

$$\lambda^{**}_{1Y} = 2.043 \times 10^{-6}$$

$$\lambda_{XMTR_{CSE_{RF}}}: \quad \begin{aligned} \lambda_{2} &= 6.734 \times 10^{-6} \\ \lambda_{5} &= 0.686 \times 10^{-6} \\ \lambda_{3B} &= 0.427 \times 10^{-6} \\ \lambda_{3G} &= 1.302 \times 10^{-6} \\ \lambda_{10E1} &= 0.466 \times 10^{-6} \\ \lambda_{11} &= 1.231 \times 10^{-6} \\ \hline \lambda_{XMTR_{CSE_{RF}}} &= 10.85 \times 10^{-6} \end{aligned}$$

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CSE_{RF}}} = (5.065 \times 10^{-6} \cdot 168\ HR)^2 + 1.140 \times 10^{-6} \cdot 168\ HR$$
$$= 7.24 \times 10^{-7} + 1.915 \times 10^{-4} = 1.92 \times 10^{-4}$$

$$P_{NF_{RF}} = (3.822 \times 10^{-6} + 0.262 \times 10^{-6} + 2.043 \times 10^{-6}) \cdot 168\ HR = 10.29 \times 10^{-4}$$

3. PROBABILITY OF THE RADIATION OF A SIGNAL THAT IS FAULTY WITH RESPECT TO COURSE RF POWER. (CONTINUED)

$$P_{XMTR_{CSE_{RF}}} = 10.85 \times 10^{-6} \cdot 168 \text{ HR} = 18.23 \times 10^{-4}$$

$$P_{CF} = \frac{(1.92 \times 10^{-4}) \cdot (10.29 \times 10^{-4})}{18.23 \times 10^{-4} + (1.92 \times 10^{-4}) \cdot (10.29 \times 10^{-4})} = 1.08 \times 10^{-4}$$

$$P_{CSE_{RF}} = (1.08 \times 10^{-4}) \cdot (1.92 \times 10^{-4}) \cdot (10.29 \times 10^{-4}) \cdot (18.23 \times 10^{-4})$$

$$P_{CSE_{RF}} = 3.917 \times 10^{-14}$$

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CSE_{RF}}} = (5.065 \times 10^{-6} \cdot 168 \text{ HR}) + (1.367 \times 10^{-6} \cdot 168 \text{ HR})$$

$$= 8.51 \times 10^{-4} + 2.30 \times 10^{-4} = 10.81 \times 10^{-4}$$

$P_{NF_{RF}} = 1$ (Since a monitor mismatch from a near field alarm will be ignored in this case.)

$$P_{XMTR_{CSE_{RF}}} = 18.23 \times 10^{-4}$$

$$P_{CF} = \frac{10.81}{18.23 + 10.81} = 0.372$$

$$P_{CSE_{RF}} = 0.372 \cdot (10.81 \times 10^{-4}) \cdot (18.23 \times 10^{-4})$$

$$P_{CSE_{RF}} = 7.331 \times 10^{-7}$$

4. PROBABILITY OF THE RADIATION OF A SIGNAL THAT IS FAULTY WITH RESPECT TO SENSITIVITY DDM.

CALCULATION

$$P_{SEN_{DDM}} = P_{CF} \times P_{INT_{SEN}} \times P_{XMTR_{SEN}}$$

WHERE

$$P_{CF} = \frac{P_{INT_{SEN}}}{P_{XMTR_{SEN}} + P_{INT_{SEN}}}$$

P_{CF} is a conditional factor, as previously described.

$$P_{INT_{SEN}} = (\lambda_{MON_{SEN}} \cdot MI)^{MM} + \lambda_{1MON} \cdot MI$$

$P_{INT_{SEN}}$ is the probability of failure of course width sensitivity DDM integral monitoring circuitry (hidden failure).

$$P_{XMTR_{SEN}} = \lambda_{XMTR_{SEN}} \cdot MI$$

$P_{XMTR_{SEN}}$ is the probability that an actual faulty course width signal will be radiated while no other parameters are affected.

MI = Maintenance interval (168 hours assumed)

$$MM = \begin{cases} 2 - & \text{If landings are not allowed with a monitor mismatch condition present (ABN light in tower).} \\ 1 - & \text{Otherwise.} \end{cases}$$

FAILURE RATE DATA

$$\lambda_{MON_{SEN}} = \lambda^*_{37B} = \lambda^*_{38B} = 3.121 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda_{1MON} = 1.140 \times 10^{-6}$$

OTHERWISE:

$$\lambda_{1MON} = 1.367 \times 10^{-6}$$

4. PROBABILITY OF THE RADIATION OF A SIGNAL THAT IS FAULTY WITH RESPECT TO SENSITIVITY DDM. (CONTINUED)

FAILURE RATE DATA (CONTINUED)

FOR THE TWO FREQUENCY GLIDESLOPE,

$$\lambda_{XMTR_{SEN}} = \lambda^{**}_{3G1} + \lambda^{**}_{10D} + \lambda^{**}_{11A} \qquad \text{(BASE CASE)}$$

$$= 0.5234 \times 10^{-6} + 0.2750 \times 10^{-6} + 0.0101 \times 10^{-6} = 0.8085 \times 10^{-6}$$

FOR THE ONE FREQUENCY, NULL REFERENCE GLIDESLOPE,

$$\lambda_{XMTR_{SEN}} = \lambda^{**}_{301} + \lambda^{**}_{10D} + \lambda^{**}_{11A}$$

$$= 0.5234 \times 10^{-6} + 0.2851 \times 10^{-6} + 0.0101 \times 10^{-6} = 0.8186 \times 10^{-6}$$

FOR THE ONE FREQUENCY, SIDE BAND REFERENCE GLIDESLOPE,

$$\lambda_{XMTR_{SEN}} = \lambda^{**}_{3G1} + \lambda^{**}_{10D} + \lambda^{**}_{11A}$$

$$= 0.5234 \times 10^{-6} + 0.2750 \times 10^{-6} + 0.0101 \times 10^{-6} = 0.8085 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{SEN}} = 1.92 \times 10^{-4}$$

$$P_{XMTR_{SEN}} = 0.808 \times 10^{-6} \cdot 168 \text{ HR} = 1.36 \times 10^{-4} \qquad \text{(BASE CASE)}$$

$$P_{CF} = \frac{1.92}{1.36 + 1.92} = 0.586$$

$$P_{SEN_{DDM}} = 0.586 \cdot (1.92 \times 10^{-4}) \cdot (1.36 \times 10^{-4}) = 1.525 \times 10^{-8}$$

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{SEN}} = (3.121 \times 10^{-6} \cdot 168) + 1.92 \times 10^{-4} = 7.54 \times 10^{-4}$$

$$P_{XMTR_{SEN}} = 1.36 \times 10^{-4}$$

$$P_{CF} = \frac{7.54}{1.36 + 7.54} = 0.847$$

$$P_{SEN_{DDM}} = 0.847 \cdot (7.54 \times 10^{-4}) \cdot (1.36 \times 10^{-4}) = 8.676 \times 10^{-8}$$

5. PROBABILITY OF THE RADIATION OF A FAULTY CLEARANCE SIGNAL (DDM, SDM, OR RF).

CALCULATION

$$P_{CL} = P_{CF} \times P_{INT_{CL}} \times P_{XMTR_{CL}}$$

WHERE

$$P_{CF} = \frac{P_{INT_{CL}}}{P_{XMTR_{CL}} + P_{INT_{CL}}}$$

P_{CF} is a conditional factor, as previously discussed.

$$P_{INT_{CL}} = (\lambda_{MON_{CL}} \cdot MI)^{MM} + \lambda_{1MON} \cdot MI$$

$P_{INT_{CL}}$ is the probability of a hidden failure of any of the clearance monitoring circuitry.

$$P_{XMTR_{CL}} = \lambda_{XMTR_{CL}} \cdot MI$$

$P_{XMTR_{CL}}$ is the probability that the radiation of the clearance signal will be faulty with respect to DDM, SDM, or RF parameters.

MI = Maintenance interval (168 hours assumed).

$$MM = \begin{cases} 2 - & \text{If landings are not allowed with a monitor mismatch condition present (ABN light in tower).} \\ 1 - & \text{Otherwise.} \end{cases}$$

FAILURE RATE DATA

$$\lambda_{MON_{CL}} = \lambda^*_{40B} = \lambda^*_{41B} = 5.077 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$\lambda_{1MON} = 1.140 \times 10^{-6}$$

OTHERWISE:

$$\lambda_{1MON} = 1.367 \times 10^{-6}$$

5. PROBABILITY OF THE RADIATION OF A FAULTY CLEARANCE SIGNAL (DDM, SDM OR RF). (CONTINUED)

FAILURE RATE DATA (CONTINUED)

$$\lambda_{XMTR_{CL}}: \quad \begin{aligned} \lambda_{4A} &= 1.914 \times 10^{-6} \\ \lambda_{4B} &= 6.734 \times 10^{-6} \\ \lambda_{3H} &= 1.176 \times 10^{-6} \\ \lambda_{10E1} &= 0.466 \times 10^{-6} \\ \lambda_{11} &= 1.231 \times 10^{-6} \\ \hline \lambda_{XMTR_{CL}} &= 11.52 \times 10^{-6} \end{aligned}$$

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CL}} = 1.92 \times 10^{-4}$$

$$P_{XMTR_{CL}} = 11.52 \times 10^{-6} \cdot 168 \text{ HR} = 19.35 \times 10^{-4}$$

$$P_{CF} = \frac{1.92}{19.35 + 1.92} = 9.03 \times 10^{-2}$$

$$P_{CL} = (9.03 \times 10^{-2}) \cdot (1.92 \times 10^{-4}) \cdot (19.35 \times 10^{-4}) = 3.363 \times 10^{-8}$$

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{INT_{CL}} = (5.077 \times 10^{-6} \cdot 168) + 1.92 \times 10^{-4} = 10.45 \times 10^{-4}$$

$$P_{XMTR_{CL}} = 19.35 \times 10^{-4}$$

$$P_{CF} = \frac{10.45}{19.35 + 10.45} = 0.35$$

$$P_{CL} = (0.35) \cdot (1.45 \times 10^{-4}) \cdot (19.35 \times 10^{-4}) = 7.522 \times 10^{-7}$$

6. PROBABILITY OF THE RADIATION OF A FAULTY SIGNAL, DUE TO ANTENNA TOWER MISALIGNMENT.

CALCULATION

$$P_{ATM} = P_{CF} \times P_{MD} \times P_{TM} + P_{TM_{DELAY}}$$

WHERE

$$P_{CF} = \frac{P_{MD}}{P_{TM} + P_{MD}}$$

P_{CF} is a conditional factor, as previously described.

$$P_{MD} = \lambda_{MD} \cdot MI$$

P_{MD} is the probability of the loss of tower misalignment detection and not producing an alarm (no "abnormal" light in tower).

P_{TM} is unpredictable, being a function of external and uncontrollable forces.

P_{TM} is the probability that the glideslope antenna tower will become misaligned within the preventive maintenance interval.

$$P_{TM_{DELAY}} = P_{TM} \cdot \frac{135 \text{ SEC}}{MI}$$

$P_{TM_{DELAY}}$ is the probability that the glideslope antenna tower will become misaligned within the 135 second delay of the misalignment detector alarm.

MI = Maintenance interval (168 hours assumed)

$$\lambda_{MD} = \lambda_{49B} + \lambda_{1Z}^{**} = 2.354 \times 10^{-6} + 0.908 \times 10^{-6} = 3.262 \times 10^{-6}$$

IF LANDINGS ARE NOT ALLOWED WITH "ABN" LIGHT ON:

$$P_{MD} = 3.262 \times 10^{-6} \cdot 168 \text{ HR} = 5.480 \times 10^{-4}$$

$$P_{TM} = 0 \quad \text{(Base case assumption)}$$

$$P_{TM_{DELAY}} = P_{TM} \cdot \left(\frac{135}{3600} \right) \div 168 = 0 \cdot 2.23 \times 10^{-4} = 0$$

$$P_{ATM} = 5.480 \times 10^{-4} \cdot 0 = 0$$

OTHERWISE:

$$P_{MD} = 1 \quad \text{("Abnormal" indication from misalignment detection is ignored.)}$$

$$P_{TM} = P_{TM_{DELAY}} = 0 \quad \text{(Base case assumption)}$$

$$P_{ATM} = 0$$

1. SINGLE FAILURES IN THE GLIDESLOPE EQUIPMENT THAT CAUSE IMMEDIATE GLIDESLOPE SHUTDOWN.

CALCULATION

$$P_S = \sum \lambda_{\text{SINGLE FAILURES}} \times T_C$$

$\lambda_{\text{SINGLE FAILURES}}$:

$$\lambda^*_{1A2} = 1.829 \times 10^{-6}$$
$$\lambda^*_{1B} = 2.982 \times 10^{-6}$$
$$\lambda^*_{1M} = 1.039 \times 10^{-6}$$
$$\lambda^*_{1AA} = 0.88 \times 10^{-6}$$
$$\lambda_{10E} = 1.951 \times 10^{-6}$$
$$\lambda_{11} = 1.231 \times 10^{-6}$$
$$\lambda_{12} = 0.778 \times 10^{-6}$$
$$\lambda_{18} = 0.098 \times 10^{-6}$$
$$\lambda_{17A} = 0.100 \times 10^{-6}$$
$$\lambda_{28} = 1.115 \times 10^{-6}$$
$$\lambda_{19} = 1.115 \times 10^{-6}$$
$$\lambda_{22} = 1.115 \times 10^{-6}$$
$$\lambda_{25} = 1.115 \times 10^{-6}$$

$$\sum \lambda = 15.348 \times 10^{-6}$$

T_C = CRITICAL LANDING TIME INTERVAL

FOR A CRITICAL INTERVAL OF 15 SECONDS:

$$P_S = 15.348 \times 10^{-6} \cdot 15 \text{ SEC}$$
$$= (15.348 \times 10^{-6}) \cdot 15/3600$$
$$P_S = 6.395 \times 10^{-8}$$

2. FAILURE IN THE MAIN TRANSMITTING UNIT AND A FAILURE IN THE STANDBY TRANSMITTING UNIT. BOTH FAILURES OCCUR WITHIN THE CRITICAL PHASE OF THE LANDING (15 SECONDS FOR GLIDESLOPE), AND IT IS IMMATERIAL WHICH FAILURE OCCURS FIRST.

CALCULATION

$$P_{AB} = P_{A+T} \times P_B$$

WHERE

P_{A+T} is the probability of loss of the main transmitting unit or spontaneous transfer due to single failures in the control unit.

P_B is the probability of loss of the standby transmitting unit.

$$P_{AB} = \left[(\lambda_A + \lambda^*_{1A1}) \ T_C \right] \cdot (\lambda_B \cdot T_C)$$

$$\lambda^*_{1A1} = 3.18 \times 10^{-6}$$

λ_A:

$$\lambda_2 = 6.734 \times 10^{-6}$$
$$\lambda_{4A} = 1.914 \times 10^{-6}$$
$$\lambda_{4B} = 6.734 \times 10^{-6}$$
$$\lambda_5 = 0.686 \times 10^{-6}$$
$$\lambda_{3A} = 2.613 \times 10^{-6}$$
$$\lambda_{3B} = 0.427 \times 10^{-6}$$
$$\lambda_{3C} = 1.453 \times 10^{-6}$$
$$\lambda_{3F} = 12.832 \times 10^{-6}$$
$$\lambda_{3G} = 1.302 \times 10^{-6}$$
$$\lambda_{3H} = 1.176 \times 10^{-6}$$
$$\lambda_{10B} = 0.134 \times 10^{-6}$$
$$\lambda_{10D} = 0.070 \times 10^{-6}$$
$$\lambda_A = 36.07 \times 10^{-6}$$

λ_B:

$$\lambda_6 = 6.734 \times 10^{-6}$$
$$\lambda_{8A} = 1.914 \times 10^{-6}$$
$$\lambda_{8B} = 6.734 \times 10^{-6}$$
$$\lambda_9 = 0.686 \times 10^{-6}$$
$$\lambda_{7A} = 2.613 \times 10^{-6}$$
$$\lambda_{7B} = 0.427 \times 10^{-6}$$
$$\lambda_{7C} = 1.453 \times 10^{-6}$$
$$\lambda_{7F} = 12.832 \times 10^{-6}$$
$$\lambda_{7G} = 1.302 \times 10^{-6}$$
$$\lambda_{7H} = 1.176 \times 10^{-6}$$
$$\lambda_{10B} = 0.134 \times 10^{-6}$$
$$\lambda_B = 36.01 \times 10^{-6}$$

$$P_{AB} = (39.25 \times 10^{-6} \cdot 15 \text{ SEC}) \cdot (36.01 \times 10^{-6} \cdot 15 \text{ SEC})$$
$$P_{AB} = 2.453 \times 10^{-14}$$

3. A HIDDEN FAILURE IN THE EQUIPMENT WHICH ESSENTIALLY INHIBITS THE TRANSFER CAPABILITY OF THE TRANSMITTING UNITS AND THEN A FAILURE IN THE MAIN TRANSMITTING UNIT.

CALCULATION

$$P_{AC} = \frac{\lambda_C}{\lambda_A + \lambda_C} \times (P_A \times P_C)$$

WHERE

P_A is the probability of the loss of the main transmitting unit.

P_C is the probability of the loss of the transfer to standby capability.

$\frac{\lambda_C}{\lambda_A + \lambda_C}$ is the conditional probability that the hidden failure modes (λ_C) will occur prior to a main transmitting unit failure that initiates a transfer (λ_A).

$$P_A = \lambda_A \cdot T_C = (36.07 \times 10^{-6}) \cdot 15 \text{ SEC} = 1.50 \times 10^{-7}$$

$$P_C = \lambda_C \cdot MI = \lambda_C \cdot 168 \text{ HR}$$

$$\lambda_C = \lambda^*_{1D3} + \lambda_{1T} + \lambda_{10A}$$

$$\lambda^*_{1D3} = 1.730 \times 10^{-6}$$

$$\lambda_{1T} = 0.545 \times 10^{-6}$$

$$\lambda_{12A} = 0.22 \times 10^{-6}$$

$$\lambda_C = 2.495 \times 10^{-6}$$

$$P_C = (2.495 \times 10^{-6}) \cdot 168 = 4.192 \times 10^{-4}$$

$$P_{AC} = \frac{2.495}{2.495 + 36.07} \cdot (4.192 \times 10^{-4}) \cdot (1.50 \times 10^{-7}) = 4.075 \times 10^{-12}$$

4. A FAILURE THAT WILL RESULT IN THE GENERATION OF A FAULTY COURSE DDM, SDM OR RF PARAMETER FROM THE STANDBY TRANSMITTING UNIT, FOLLOWED BY ANY FAILURE IN THE MAIN TRANSMITTER OR CONTROL UNIT WHICH CAN INITIATE A TRANSFER..

CALCULATION

$$P_{STBY_{CSE}} = \left(\frac{\lambda_{B_{CSE}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{CSE}}}\right) X P_{B_{CSE}} \; X P_{A+T}$$

WHERE

$P_{B_{CSE}}$ is the probability of a failure that will result in the generation of a faulty course DDM, SDM or RF parameter from the standby transmitter.

P_{A+T} is the probability of loss of the main transmitting unit or spontaneous transfer due to single failures in the control unit (previously identified).

$\left(\frac{\lambda_{B_{CSE}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{CSE}}}\right)$ is the conditional probability that the standby transmitter failure modes ($\lambda_{B_{CSE}}$) will occur prior to a transmitter or control unit failure that initiates a transfer ($\lambda_A + \lambda^*_{1A1}$).

$$\lambda_{B_{CSE}}: \quad \begin{aligned} \lambda_6 &= 6.734 \times 10^{-6} \\ \lambda_9 &= 0.686 \times 10^{-6} \\ \lambda_{7B} &= 0.427 \times 10^{-6} \\ \lambda_{7F} &= 12.832 \times 10^{-6} \\ \lambda_{7G} &= 1.302 \times 10^{-6} \\ \hline \lambda_{B_{CSE}} &= 21.98 \times 10^{-6} \end{aligned}$$

$$\lambda_A + \lambda^*_{1A1} = 36.07 \times 10^{-6} + 3.18 \times 10^{-6} = 39.25 \times 10^{-6}$$

$$P_{B_{CSE}} = \lambda_{B_{CSE}} \cdot 168 \text{ HR} = 36.93 \times 10^{-4}$$

$$P_{A+T} = (\lambda_A + \lambda^*_{1A1}) \cdot 15 \text{ SEC} = 0.164 \times 10^{-6}$$

$$P_{STBY_{CSE}} = \frac{21.98}{39.25 + 21.98} \cdot (36.93 \times 10^{-4})(0.164 \times 10^{-6}) = 2.167 \times 10^{-10}$$

5. A FAILURE THAT WILL RESULT IN THE GENERATION OF A FAULTY COURSE WIDTH (DDM) PARAMETER FROM THE STANDBY TRANSMITTING UNIT, FOLLOWED BY ANY FAILURE IN THE MAIN TRANSMITTER OR CONTROL UNIT WHICH CAN INITIATE A TRANSFER.

CALCULATION

$$P_{STBY_{SEN}} = \frac{\lambda_{B_{SEN}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{SEN}}} \times P_{B_{SEN}} \times P_{A+T}$$

WHERE

$P_{B_{SEN}}$ is the probability of a failure that will result in the generation of a faulty course width (DDM) parameter from the standby transmitter.

P_{A+T} - previously identified

$\frac{\lambda_{B_{SEN}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{SEN}}}$ is a conditional probability factor, as previously discussed.

$$\lambda_{B_{SEN}} = \lambda_{7B} + \lambda_{7F} + \lambda_{7G}$$

$$= 0.427 \times 10^{-6} + 12.832 \times 10^{-6} + 1.302 \times 10^{-6} = 14.56 \times 10^{-6}$$

$$\lambda_A + \lambda^*_{1A1} = 39.25 \times 10^{-6}$$

$$P_{B_{SEN}} = \lambda_{B_{SEN}} \cdot 168 \text{ HR} = 24.46 \times 10^{-4}$$

$$P_{A+T} = (\lambda_A + \lambda^*_{1A1}) \cdot 15 \text{ SEC} = 0.164 \times 10^{-6}$$

$$P_{STBY_{SEN}} = \frac{14.56}{39.25 + 14.56} \cdot (24.46 \times 10^{-4}) \cdot (0.164 \times 10^{-6}) = 1.082 \times 10^{-10}$$

6. A FAILURE THAT WILL RESULT IN THE GENERATION OF A FAULTY CLEARANCE DDM, SDM OR RF PARAMETER FROM THE STANDBY TRANSMITTING UNIT, FOLLOWED BY ANY FAILURE IN THE MAIN TRANSMITTER OR CONTROL UNIT WHICH CAN INITIATE A TRANSFER.

CALCULATION

$$P_{STBY_{CL}} = \left(\frac{\lambda_{B_{CL}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{CL}}}\right) X\ P_{B_{CL}}\ X\ P_{A+T}$$

WHERE

$P_{B_{CL}}$ is the probability of a failure that will result in the generation of a faulty clearance DDM, SDM or RF parameter from the standby transmitter.

P_{A+T} - previously identified

$\left(\frac{\lambda_{B_{CL}}}{\lambda_A + \lambda^*_{1A1} + \lambda_{B_{CL}}}\right)$ is a conditional probability factor, as previously discussed.

$$\lambda_{B_{CL}}: \quad \lambda_{8A} = 1.914 \times 10^{-6}$$

$$\lambda_{8B} = 6.734 \times 10^{-6}$$

$$\lambda_{7H} = 1.176 \times 10^{-6}$$

$$\lambda_{B_{CL}} = 9.82 \times 10^{-6}$$

$$\lambda_A + \lambda^*_{1A1} = 39.25 \times 10^{-6}$$

$$P_{B_{CL}} = \lambda_{B_{CL}} \cdot 168\ HR = 16.50 \times 10^{-4}$$

$$P_{A+T} = (\lambda_A + \lambda^*_{1A1}) \cdot 15\ SEC = 0.164 \times 10^{-6}$$

$$P_{STBY_{CL}} = \frac{9.82}{39.25 + 9.82} \cdot (16.50 \times 10^{-4}) \cdot (0.164 \times 10^{-6}) = 5.399 \times 10^{-11}$$

7. A FAILURE THAT WILL RESULT IN THE GENERATION OF ANY FAULTY PARAMETER OF THE STANDBY TRANSMITTING UNIT, FOLLOWED BY ANY FAILURE IN THE MAIN TRANSMITTER OR CONTROL UNIT WHICH CAN INITIATE A TRANSFER.

CALCULATION

$$P_{STBY} = \frac{\lambda_B}{\lambda_A + \lambda^*_{1A1} + \lambda_B} \times (\lambda_B \cdot 168) \times P_{A+T}$$

WHERE

P_{A+T} - previously identified

$\frac{\lambda_B}{\lambda_A + \lambda^*_{1A1} + \lambda_B}$ is a conditional probability factor, as previously discussed.

$$\lambda_B = 36.01 \times 10^{-6}$$

$$\lambda_A + \lambda^*_{1A1} = 39.25 \times 10^{-6}$$

$$\lambda_B \cdot 168 \text{ HR} = 62.58 \times 10^{-4}$$

$$P_{A+T} = (\lambda_A + \lambda^*_{1A1}) \cdot 15 \text{ SEC} = 0.164 \times 10^{-6}$$

$$P_{STBY} = \frac{36.01}{39.25 + 36.01} \cdot (62.58 \times 10^{-4}) \cdot (0.164 \times 10^{-6}) = 4.983 \times 10^{-10}$$

8. CONVERTER FAILURES LEADING TO A SHUTDOWN.

CALCULATION

$$P_{CONV} = (\lambda_{15} \times 720\,HR)^{1} \times (\lambda_{16} \times 15\ SEC)$$

WHERE

P_{CONV} is the probability of both main converters failing.

$\lambda_{15} = \lambda_{16} = 6.598 \times 10^{-6}$

$$P_{CONV} = 1.306 \times 10^{-10}$$

[1] A monthly preventive maintenance cycle is assumed for power supply systems.

9. BOTH COURSE MONITORS FAILING, PRODUCING AN ALARM.

CALCULATION

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{CSE} = (\lambda_{CSE} \cdot T_C)^2 \qquad \text{(CASE 1)}$$

OTHERWISE:

$$P_{CSE} = (\lambda_{CSE} \cdot 168)(\lambda_{CSE} \cdot T_C) \qquad \text{(CASE 2)}$$

$$\lambda_{CSE} = \lambda_{CSE1} = \lambda_{CSE2}$$

$$\lambda_{CSE1} = \lambda^{*}_{34A} = 12.918 \times 10^{-6}$$

$$P_{CSE} = (12.918 \times 10^{-6} \cdot 15\ SEC)^2 = 2.897 \times 10^{-15} \qquad \text{(CASE 1)}$$

$$P_{CSE} = (12.918 \times 10^{-6} \cdot 168\ HR)\ (12.918 \times 10^{-6} \cdot 15\ SEC)\ 1.168 \times 10^{-10} \qquad \text{(CASE 2)}$$

10. BOTH SENSITIVITY MONITORS FAILING, PRODUCING AN ALARM.

CALCULATION

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{SEN} = (\lambda_{SEN} \cdot T_C)^2 \qquad \text{(CASE 1)}$$

OTHERWISE:

$$P_{SEN} = (\lambda_{SEN} \cdot 168\ HR)(\lambda_{SEN} \cdot T_C) \qquad \text{(CASE 2)}$$

$$\lambda_{SEN} = \lambda_{SEN1} = \lambda_{SEN2}$$

$$\lambda_{SEN1} = \lambda^*_{37A} = 9.596 \times 10^{-6}$$

$$P_{SEN} = (9.60 \times 10^{-6} \cdot 15\ SEC)^2 = 1.598 \times 10^{-15} \qquad \text{(CASE 1)}$$

$$P_{SEN} = (9.60 \times 10^{-6} \cdot 168\ HR)(9.60 \cdot 15\ SEC) = 6.445 \times 10^{-11} \qquad \text{(CASE 2)}$$

11. BOTH CLEARANCE MONITORS FAILING, PRODUCING AN ALARM.

CALCULATION

IF LANDINGS ARE ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{CL} = (\lambda_{CL} \cdot T_C)^2 \qquad \text{(CASE 1)}$$

OTHERWISE:

$$P_{CL} = (\lambda_{CL} \cdot 168\ HR)(\lambda_{CL} \cdot T_C) \qquad \text{(CASE 2)}$$

$$\lambda_{CL} = \lambda_{CL1} = \lambda_{CL2}$$

$$\lambda_{CL1} = \lambda^*_{40A} = 13.273 \times 10^{-6}$$

$$P_{CL} = (13.27 \times 10^{-6} \cdot 15\ SEC)^2 = 3.058 \times 10^{-15} \qquad \text{(CASE 1)}$$

$$P_{CL} = (13.27 \times 10^{-6} \cdot 168\ HR)(13.27 \cdot 15\ SEC) = 1.233 \times 10^{-10} \qquad \text{(CASE 2)}$$

12. BOTH NEAR FIELD MONITORS/PEAK DETECTORS FAILING, PRODUCING AN ALARM.

CALCULATION

IF LANDINGS ARE NOT ALLOWED WITH A MONITOR MISMATCH CONDITION PRESENT:

$$P_{NF} = (\lambda_{NF} \cdot T_C)^2 \qquad \text{(CASE 1)}$$

OTHERWISE:

$$P_{NF} = (\lambda_{NF} \cdot 168\ HR)(\lambda_{NF} \cdot T_C) \qquad \text{(CASE 2)}$$

$$\lambda_{NF} = \lambda_{NF1} = \lambda_{NF1}$$

$$\lambda_{NF1}: \quad \lambda_{43A} = 11.099 \times 10^{-6}$$

$$\lambda_{28} = 1.115 \times 10^{-6}$$

$$\lambda_{NF1} = 12.26 \times 10^{-6}$$

$$P_{NF} = (12.26 \times 10^{-6} \cdot 15\ SEC)^2 = 2.609 \times 10^{-15} \qquad \text{(CASE 1)}$$

$$P_{NF} = (12.26 \times 10^{-6} \cdot 168\ HR)(12.26 \times 10^{-6} \cdot 15\ SEC) = 1.052 \times 10^{-10} \qquad \text{(CASE 2)}$$