INTEGRATED AVIONICS RELIABILITY

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INTRODUCTION

The integrated avionics reliability task is an effort to build credible reliability/performability models for multisensor integrated navigation and flight control. The 1986 research was initiated by the reliability analysis of a multisensor navigation system consisting of the Global Positioning System (GPS), the Long Range Navigation system (Loran-C), and an inertial measurement unit (IMU). Markov reliability models were developed based on system failure rates and mission time.

Figure 1 shows the mechanization of the multisensor navigation system based on GPS, Loran-C, and an IMU. Each sensor is implemented with triple redundancy. The decision making logic determines which sensors are to be used for navigation based on the Kalman filter residuals. Figure 2 depicts the state transition diagram for the multisensor system. The corresponding 16-state Markov model is shown in figure 3, with the assumption that no repairs are made during system operation.

In order to obtain position information from the IMU both the accelerometers and the gyros are needed. Using this information, the state transition diagram can be reduced to eight states as depicted in figure 4. The corresponding reduced Markov model is shown in figure 5. From the state transition matrix the stochastic probability matrix (SPM) can be obtained. The elements of the SPM represent the probabilities that the system will remain in a certain state (diagonal elements) and the probabilities that the system will make a transition to another state (off-diagonal elements). The SPM for the integrated navigation system is given in figure 6 along with the reliability formulas.

Starting the system from the initial state probability vector P(0), the state probabilities for some time later can be found by multiplying the state probability vector by the stochastic probability matrix. The number of multiplications is determined by the quotient of the mission time and the time interval between state updates.

As an example, consider the configuration as depicted in figure 1 and assume that the mean time between failure for each sensor is equal to 4,500 hours. It then follows that the probability of system failure during a mission with a duration of one hour is approximately one part in one hundred billion.

DISCRETE MARKOV CHAIN COMPRESSION METHOD

Markov analysis is based on the Stochastic Probability Matrix (SPM). The dimension of the SPM is determined by the nth power of two, where n is the number of sensors in the system. For example, if a system consists of eight sensors, the dimension of the SPM is 256 by 256. Manipulation of matrices of this size is rather complicated.

A solution to the manipulation of large stochastic matrices was found by separating the sensors into statistically independent sets; i.e. the Discrete Markov Chain Compression Method (DMCCM). Figure 7 illustrates the DMCCM, the sensors are separated in sets and individual Markov models are made for the corresponding sets. The output of each smaller Markov model represents the failure probability for the given sensor set. All those outputs are merged into smaller size models again, until a single output is produced. The final (single) output represents the failure probability of the last system state for the specified mission time. This is also the probability that the system will have a total failure during the given mission time. A detailed description of the DMCCM can be found in reference 1.

FUTURE RESEARCH

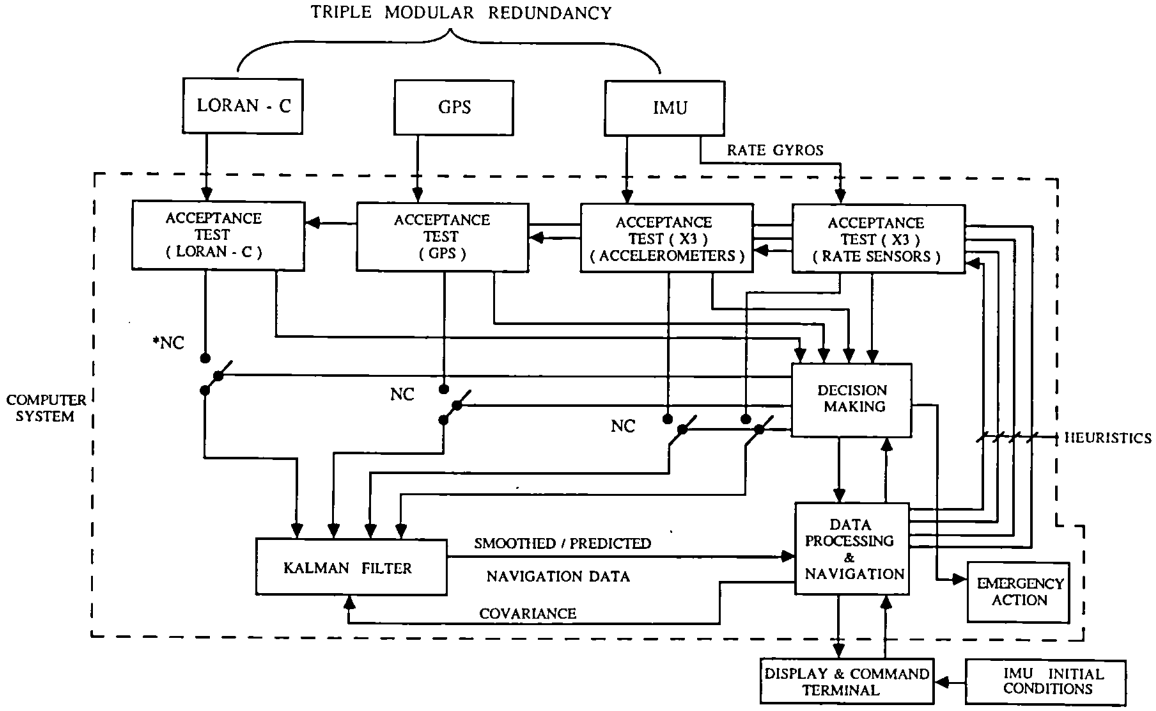
Next year's reliability effort is defined with input from NASA Langley Research Center. This effort deals with the creation of a generic reliability tool for flight control systems operating in the terminal area. Figure 8 shows a multisensor flight control baseline system for terminal area guidance. The reliability model for this system is depicted in figure 9. The attitude, air data, and navigation aids are in series for the reliability evaluation since the system will fail if any of these three components fails.

In addition to the evaluation of a more complex avionics system, the system will also be allowed to incorporate fault detection and isolation (FDI) techniques (ref. 2). Adding FDI to the system increases the complexity of the reliability evaluation tremendously. This is illustrated in figures 10 and 11. Figure 10 shows the Markov model for a two-sensor system without FDI. Adding probabilities of fault detection, isolation, transient recovery, false alarm, and damage results in the Markov model shown in figure 11.

REFERENCES

1. Alikiotis, D. M.: Discrete Markov Chain Compression Method. Ohio University, Avionics Engineering Center, Report No. OU/AEC 6-86TM-TRIU109, June 1986.

2. Caglayan, A. K. and Lancraft, R. E.: An Aircraft Sensor Fault Tolerant System. NASA CR-165876, April 1982.



*NC = NORMALLY CLOSED

Figure 1. Multisensor navigation system mechanization for reliability analysis of an integrated GPS, Loran-C, and inertial measurement unit system.

STATE	DEFINITION
1	GYROS, ACCEL, GPS, LORAN
2	GYROS, ACCEL, GPS, $\overline{\text{LORAN}}$
3	GYROS, ACCEL, $\overline{\text{GPS}}$, LORAN
4	GYROS, $\overline{\text{ACCEL}}$, GPS, LORAN
5	$\overline{\text{GYROS}}$, ACCEL, GPS, LORAN
6	$\overline{\text{GYROS}}$, ACCEL, GPS, $\overline{\text{LORAN}}$
7	GYROS, ACCEL, $\overline{\text{GPS}}$, $\overline{\text{LORAN}}$
8	GYROS, $\overline{\text{ACCEL}}$, GPS, $\overline{\text{LORAN}}$
9	GYROS, $\overline{\text{ACCEL}}$, $\overline{\text{GPS}}$, LORAN
10	$\overline{\text{GYROS}}$, ACCEL, $\overline{\text{GPS}}$, LORAN
11	$\overline{\text{GYROS}}$, $\overline{\text{ACCEL}}$, GPS, LORAN
12	GYROS, $\overline{\text{ACCEL}}$, $\overline{\text{GPS}}$, $\overline{\text{LORAN}}$
13	$\overline{\text{GYROS}}$, ACCEL, $\overline{\text{GPS}}$, $\overline{\text{LORAN}}$
14	$\overline{\text{GYROS}}$, $\overline{\text{ACCEL}}$, GPS, $\overline{\text{LORAN}}$
15	$\overline{\text{GYROS}}$, $\overline{\text{ACCEL}}$, $\overline{\text{GPS}}$, LORAN
16	$\overline{\text{GYROS}}$, $\overline{\text{ACCEL}}$, $\overline{\text{GPS}}$, $\overline{\text{LORAN}}$

GYROS - GYROS GOOD
$\overline{\text{GYROS}}$ - GYROS FAILED
ACCEL - ACCELEROMETERS GOOD
$\overline{\text{ACCEL}}$ - ACCELEROMETERS FAILED
GPS - GPS GOOD
$\overline{\text{GPS}}$ - GPS FAILED
LORAN - LORAN-C GOOD
$\overline{\text{LORAN}}$ - LORAN-C FAILED

Figure 2. State transition diagram for the reliability analysis of a multisensor navigation system based on GPS, Loran-C, and and an inertial measurement unit.

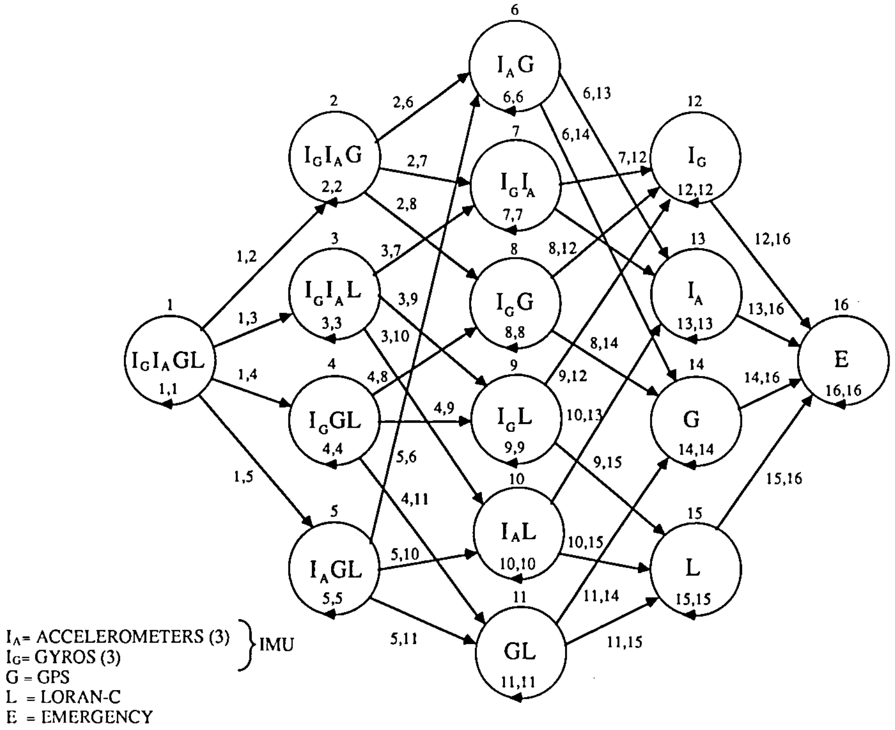


Figure 3. Sixteen-state Markov model for the reliability analysis of an integrated navigation system based on GPS, Loran-C, and and an inertial measurement unit.

STATE	DEFINITION
1	IMU, GPS, LORAN
2	IMU, GPS, $\overline{\text{LORAN}}$
3	$\overline{\text{IMU}}$, GPS, LORAN
4	IMU, $\overline{\text{GPS}}$, LORAN
5	IMU, $\overline{\text{GPS}}$, $\overline{\text{LORAN}}$
6	$\overline{\text{IMU}}$, GPS, $\overline{\text{LORAN}}$
7	$\overline{\text{IMU}}$, $\overline{\text{GPS}}$, LORAN
8	$\overline{\text{IMU}}$, $\overline{\text{GPS}}$, $\overline{\text{LORAN}}$

IMU = INERTIAL MEASUREMENT UNIT GOOD
$\overline{\text{IMU}}$ = INERTIAL MEASUREMENT UNIT FAILED
GPS = GPS GOOD
$\overline{\text{GPS}}$ = GPS FAILED
LORAN = LORAN - C GOOD
$\overline{\text{LORAN}}$ = LORAN - C FAILED

Figure 4. Reduced state transition diagram for the reliability analysis of an integrated navigation system based on GPS, Loran-C, and an inertial measurement unit.

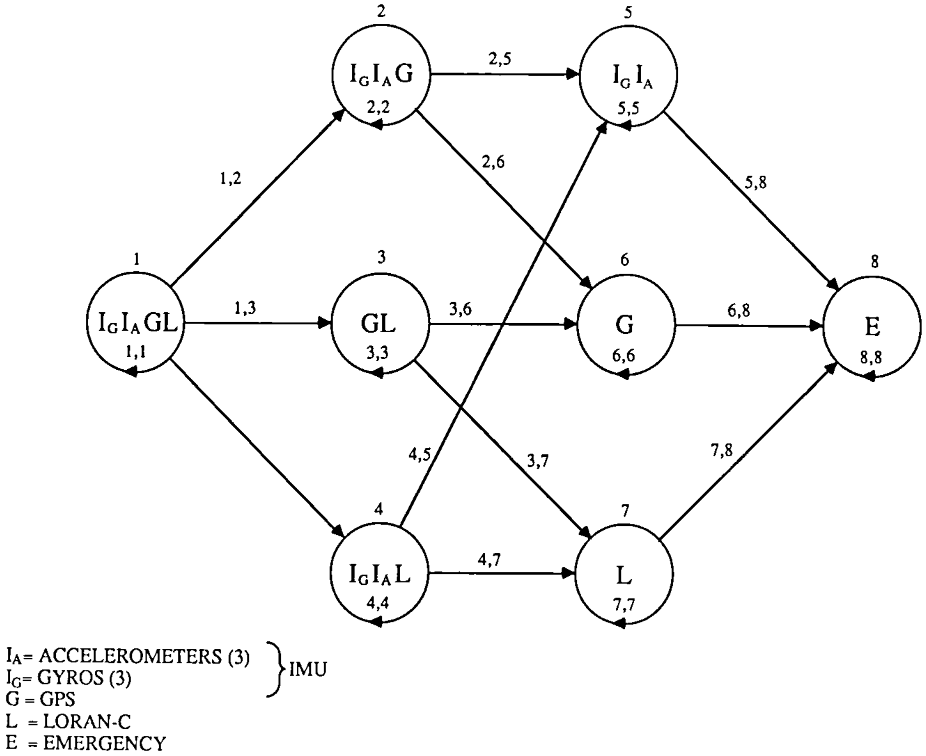


Figure 5. Reduced Markov model for the reliability analysis of an integrated navigation system based on GPS, Loran-C, and an inertial measurement unit.

FROM STATE ↓ → TO STATE

$$\begin{array}{c|cccccccc}
 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\
\hline
1 & P_{11} & P_{12} & P_{13} & P_{14} & 0 & 0 & 0 & 0 \\
2 & 0 & P_{22} & 0 & 0 & P_{25} & P_{26} & 0 & 0 \\
3 & 0 & 0 & P_{33} & 0 & P_{35} & 0 & P_{37} & 0 \\
4 & 0 & 0 & 0 & P_{44} & 0 & P_{46} & P_{47} & 0 \\
5 & 0 & 0 & 0 & 0 & P_{55} & 0 & 0 & P_{58} \\
6 & 0 & 0 & 0 & 0 & 0 & P_{66} & 0 & P_{68} \\
7 & 0 & 0 & 0 & 0 & 0 & 0 & P_{77} & P_{78} \\
8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & P_{88}
\end{array}$$

a)

$$\begin{array}{c|cccccccc}
 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\
\hline
1 & 1\text{-}p_I p_G p_L^* & p_L & p_G & p_I & 0 & 0 & 0 & 0 \\
2 & 0 & 1\text{-}p_I p_G & 0 & 0 & p_G & p_I & 0 & 0 \\
3 & 0 & 0 & 1\text{-}p_I p_L & 0 & p_L & 0 & p_I & 0 \\
4 & 0 & 0 & 0 & 1\text{-}p_G p_L & 0 & p_L & p_G & 0 \\
5 & 0 & 0 & 0 & 0 & 1\text{-}p_I & 0 & 0 & p_I \\
6 & 0 & 0 & 0 & 0 & 0 & 1\text{-}p_G & 0 & p_G \\
7 & 0 & 0 & 0 & 0 & 0 & 0 & 1\text{-}p_L & p_L \\
8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{array} = P_N$$

b)

INITIAL STATE PROBABILITY VECTOR: $P(0) = [\overset{1}{1}\ \overset{2}{0}\ \overset{3}{0}\ \overset{4}{0}\ \overset{5}{0}\ \overset{6}{0}\ \overset{7}{0}\ \overset{8}{0}]$

$^*p_i = \lambda_i . \delta(t)$, $\delta(t)$ = time interval, λ_i = failure rate for sensor i.

L = LORAN-C SENSOR
I = IMU SENSOR
G = GPS SENSOR

$P(1) = P(0)\ P_N$ → After N multiplications P(1) becomes the limiting state probability. $N = \dfrac{\text{Mission Time}}{\delta(t)}$

Figure 6. State transition matrix and reliability equations for the integrated navigation system.

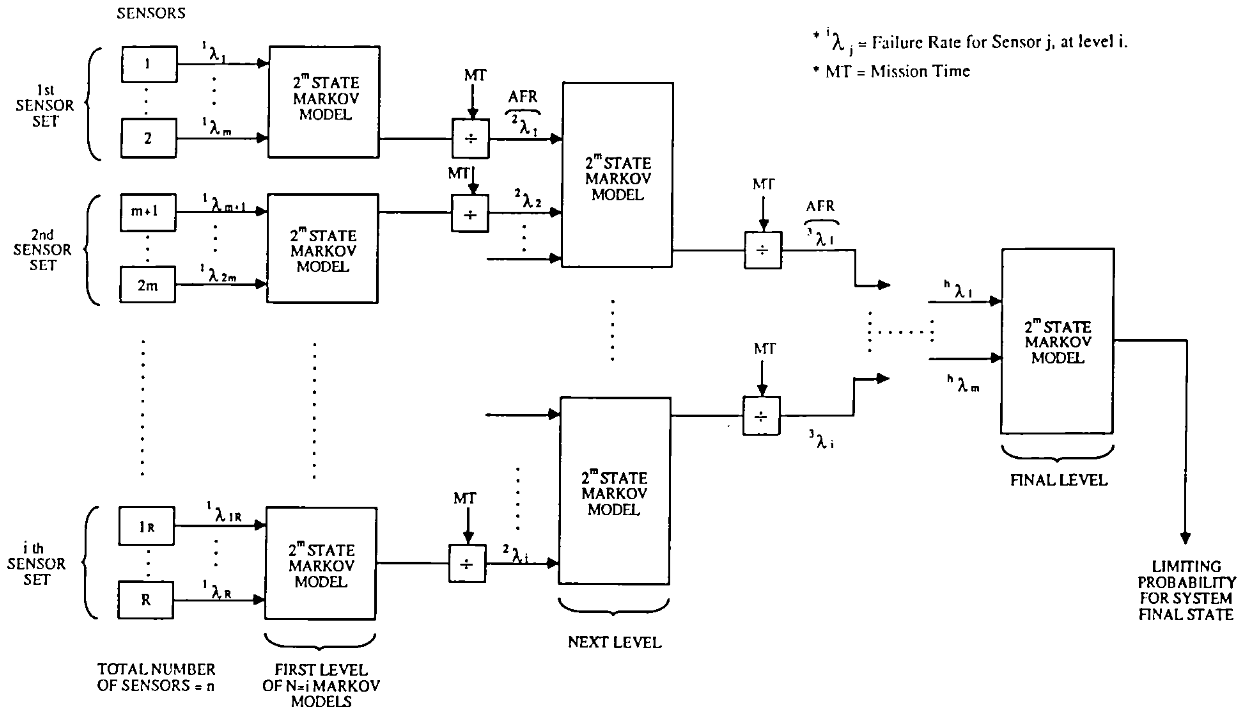


Figure 7. Functional block diagram representation of the Discrete Markov Chain Compression Method (DMCCM).

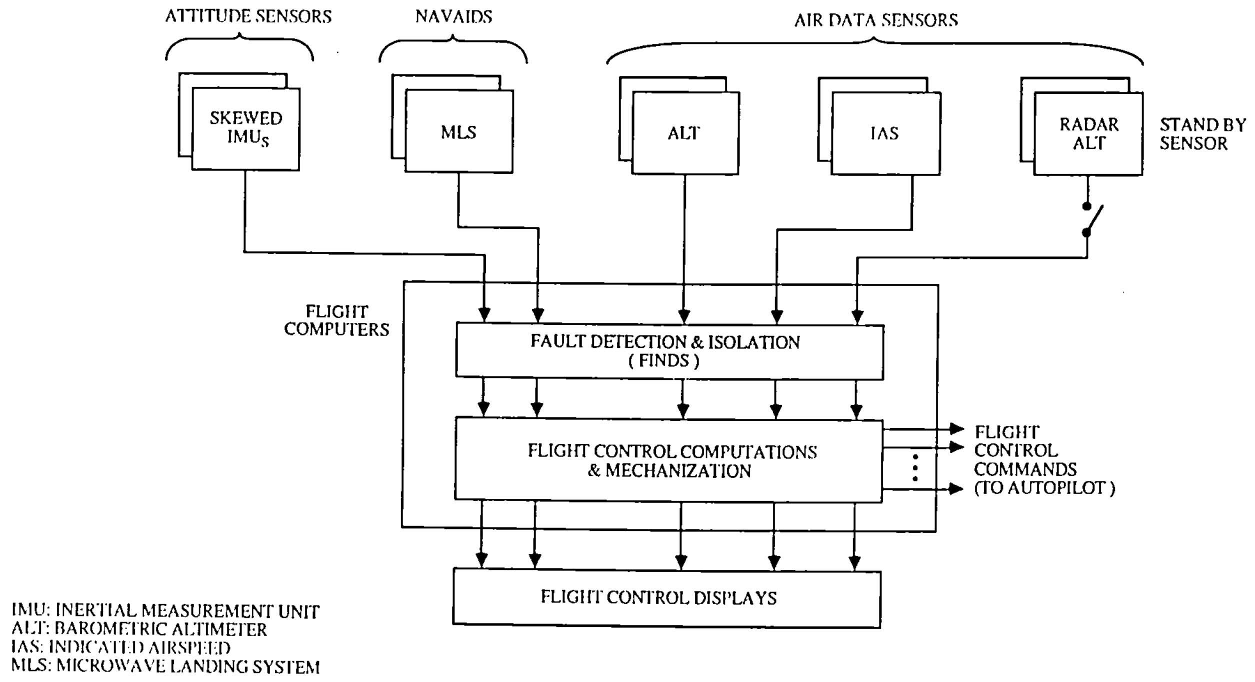


Figure 8. Multisensor flight control baseline system mechanization for terminal area guidance.

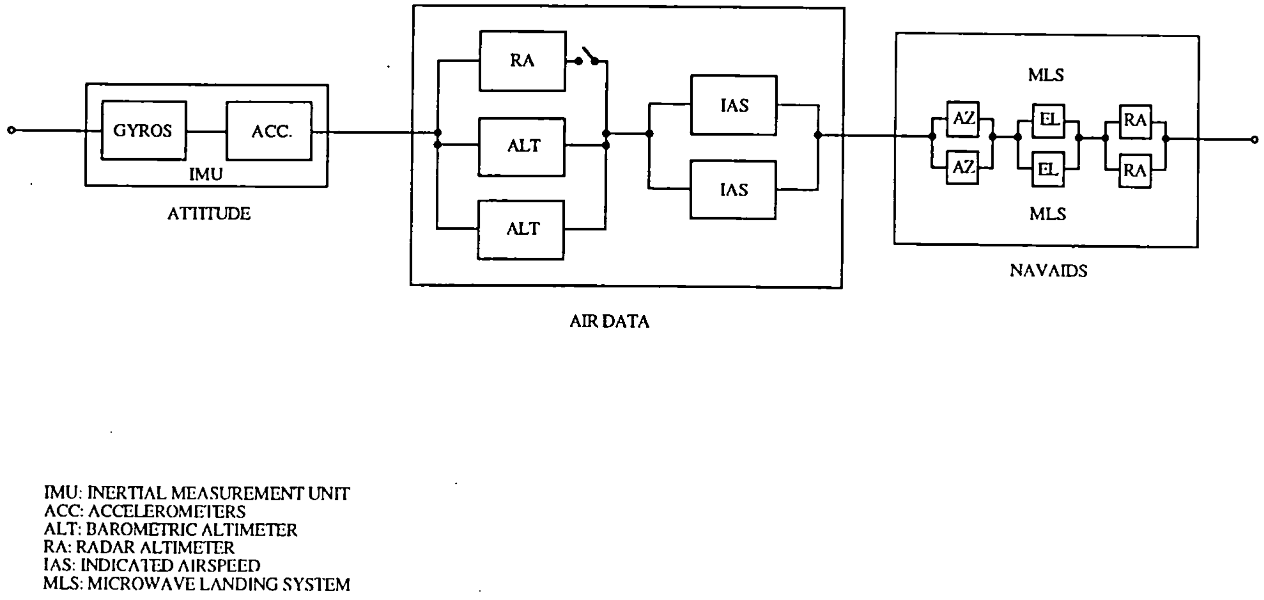


Figure 9. Reliability diagram for the multisensor flight control system.

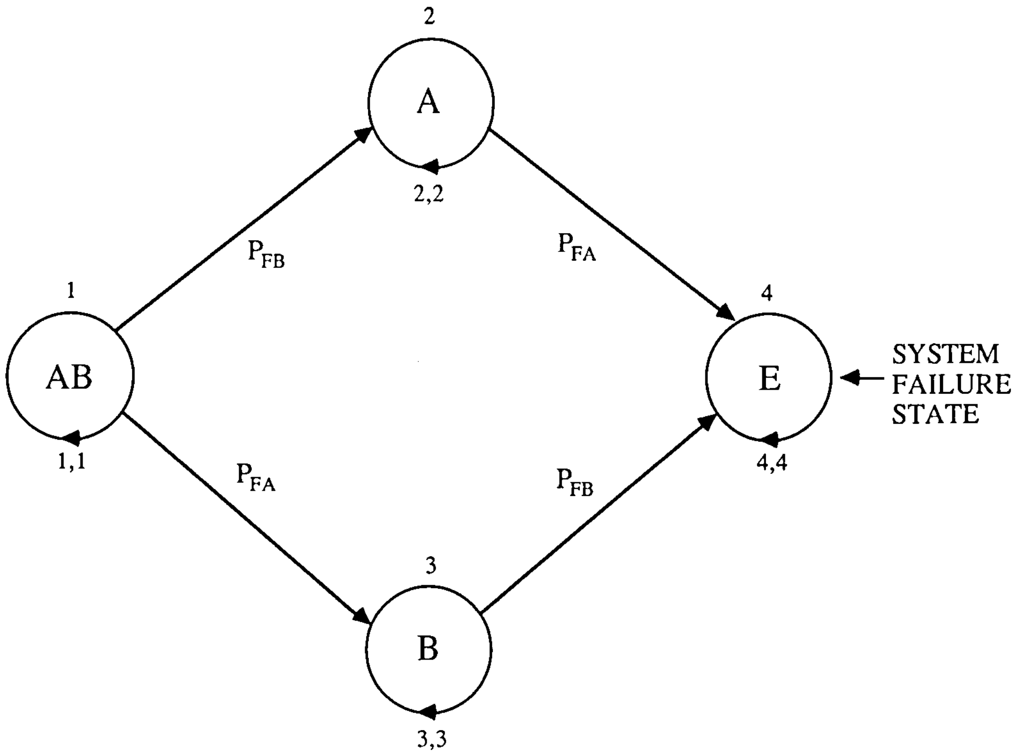
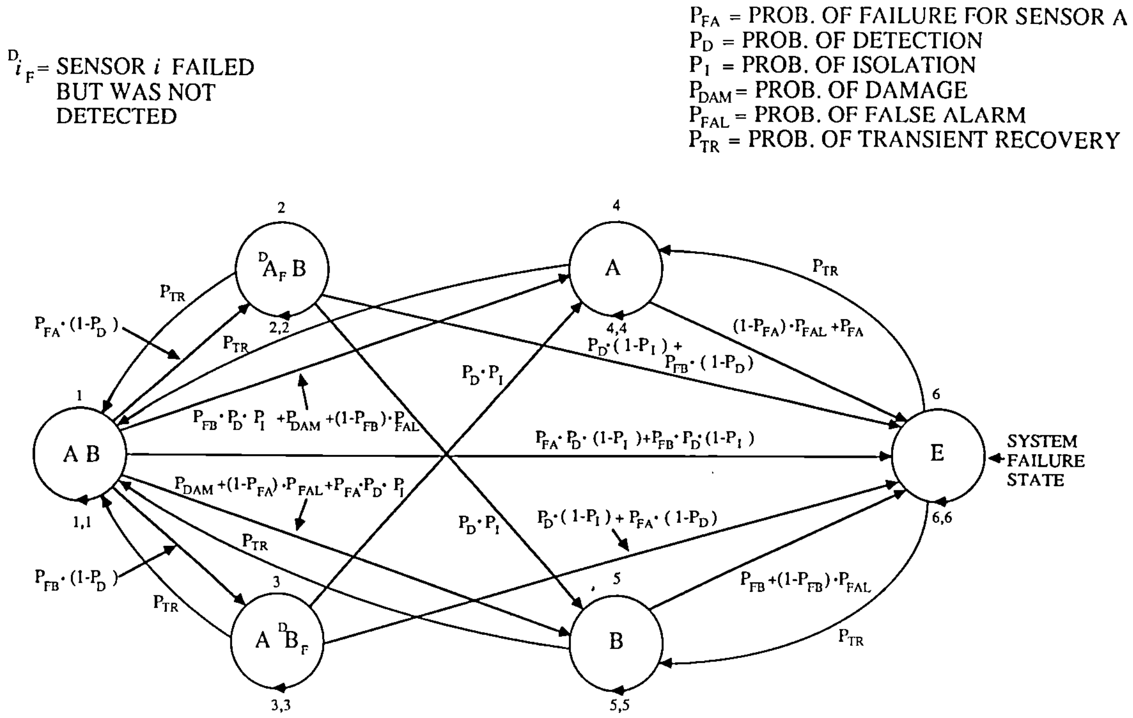


Figure 10. A two-sensor Markov model without fault detection and isolation.


${}^{D}i_F$ = SENSOR i FAILED BUT WAS NOT DETECTED

P_{FA} = PROB. OF FAILURE FOR SENSOR A
P_D = PROB. OF DETECTION
P_I = PROB. OF ISOLATION
P_{DAM} = PROB. OF DAMAGE
P_{FAL} = PROB. OF FALSE ALARM
P_{TR} = PROB. OF TRANSIENT RECOVERY

Figure 11. A two-sensor Markov model with fault detection and isolation including probabilities of failure detection, isolation, transient recovery, false alarm, and damage.

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