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B-52 STABILITY AUGMENTATION SYSTEM RELIABILITY

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SUMMARY

The B-52 SAS (Stability Augmentation System) was developed and retrofitted to nearly 300 aircraft. It actively controls B-52 structural bending, provides improved yaw and pitch damping through sensors and electronic control channels, and puts complete reliance on hydraulic control power for rudder and elevators. The system has now experienced over 300,000 flight hours and has exhibited service reliability comparable to the results of the reliability test program. Development experience points out numerous lessons with potential application in the mechanization and development of advanced technology control systems of high reliability.

INTRODUCTION

The B-52 SAS (Stability Augmentation System) was developed and retrofitted on nearly 300 aircraft in order to achieve the following objectives:

a. Minimize fatigue damage due to structure deflection in turbulence.

b. Improve capability of withstanding extremely high velocity gusts.

c. Improve yaw and pitch damping

d. Increase rudder and elevator authority.

e. Improve crew ride.

It was necessary to place unusual emphasis on system reliability, for two principal reasons:

a. On the yaw and pitch axes, replacement of the original mechanical (servo tab) system by a hydraulic actuator system introduces the possibility of total loss of rudder and elevator control in flight due to hydraulic failures.

b. The use of an electronic system with relatively high rudder and elevator authority introduces the possibility of sudden unscheduled displacements or "hardovers" of the control surfaces due to electrical faults, with obvious flight safety implications.

REDUNDANCY MANAGEMENT

Figure 1 is a simplified schematic diagram of the SAS. Yaw damping and elastic mode suppression signals are generated by combining rate gyro outputs with lateral accelerometer outputs, and the gains are scheduled according to airspeed (high gain at low airspeed and vice versa). For the pitch axis, only rate gyro signals are used; the gain is fixed and independent of airspeed. There are two essentially independent hydraulic power supplies, each having a main pump and an emergency pump. The main pumps are electrically powered; the emergency pumps are simply hydraulic transformers (motor-pump packages), driven by separate existing utility hydraulic systems and provided with flow limiters to avoid crippling the utility systems in the event of loss of fluid from a SAS system. The control surface actuators are of tandem type, normally powered by both hydraulic supplies.

The system is basically FO-FS (fail operational on first failure, fail soft on second), with the following exceptions:

a. If two lateral accelerometer channels fail, all three accelerometer channels drop out, while the yaw axis continues to operate on the yaw rate gyro signals only.

b. If two gain scheduling channels fail, all three channels revert to a low gain that is safe at all airspeeds.

These two features provide a substantial decrease in the number of two-failure combinations that can cause yaw axis disengagement or loss of function.

The basic redundancy management concept is relatively straightforward. At various points in the three-channel sensor-electronics subsystem, voters and comparators are used, as shown on Figure 2. For example, the three inputs at the left of the diagram may represent three rate gyro outputs, while the three outputs at the right may represent three channels of an electronic control unit. If any input disagrees with the median signal by more than the preselected error threshold, the comparator trips and latches itself in the tripped mode. In this mode, the comparator swamps the discrepant input so that it will not be selected by any voter as a median signal. In some cases the swamping signal is a hardover; in other cases, it is a 400 Hz square wave. Also, the comparator shuts off its normal "O.K." signal to the logic circuitry, thus preparing the logic to take proper action in the event of a subsequent second failure. On the yaw axis, the failure of one channel also sends a "channel failed" signal to the pilot, warning him that redundancy has been lost and that yaw damping will be automatically disengaged in the event of a second similar failure. Loss of yaw damping is not a highly critical failure mode, but it poses a slight threat to flight safety by requiring manual damping of Dutch roll, which may be difficult with certain adverse combinations of high gross weight, high altitude, poor visibility, and turbulence. No such warning to the pilot is required for single channel failures in accelerometer, gain scheduling, or pitch axis channels, as these pose no threat to flight safety and require no special crew action.

FLIGHT SAFETY RELIABILITY

In early discussions, Air Force representatives expressed a clear desire to state the system reliability objective in terms of aircraft loss rate. This required analysis in considerably greater depth than ordinary reliability calculations for a redundant system. It was necessary to:

a. Define each potentially critical failure mode of the system in terms of the effect on control surface motions.

b. Compute the probabilities of occurrence separately for each of these modes during each phase of a standardized mission profile.

c. Compute the probability of aircraft loss for each mode in a variety of flight conditions (altitude, airspeed, and presence of nearby aircraft such as in aerial refueling) with proper allowance for probabilities of various turbulence intensities and visibility conditions.

d. Combine the above to obtain a total predicted B-52 loss rate attributable to SAS failure.

CRITICALITIES

During the prototype program, hundreds of SAS failures were simulated in piloted flight simulators and the resulting aircraft motions were recorded. Five or more different pilots were used for each combination of SAS failure mode and flight condition. After each simulation, the pilot was asked to estimate the percentage of SAC pilots that would have been unable to avoid loss of the aircraft. The results were averaged to arrive at a probability of aircraft loss for each combination. These results were combined with the probabilities of given turbulence conditions, visibility conditions, and autopilot status to yield a criticality matrix suitable for use in the aircraft loss prediction program. Criticality, as used here, is defined as the probability of aircraft loss <u>if</u> the given system failure mode occurs during given flight conditions.

In the past, there has been a widespread tendency to treat criticality as a dichotomy. To label a failure mode as "critical" meant that it would invariably cause loss of the aircraft, and to label it as "non-critical" meant that it would never cause loss of aircraft. In other words, criticality was assigned only two possible values: zero and 100 percent. It is true, of course, that many failure modes have criticalities of zero, and some failure modes, such as gross failure of a primary structure, have criticalities of 100 percent. But in any attempt to make a realistic prediction of the flight safety reliability of a control system, it must be recognized that many of the failure modes will have intermediate criticalities. They may approach 100 percent with unfavorable combinations of flight conditions, and may be essentially zero with favorable combinations of flight conditions.

The probability of occurrence of each potentially critical system failure mode during each phase of the mission was computed using conventional methods, but with certain refinements as subsequently discussed. These probabilities of occurrence were compiled into a failure mode occurrence probability matrix. Figure 3 is a simplified diagram showing the principal factors entering into the construction of these two matrices. The two matrices are constructed and combined in a computer program to predict aircraft losses.

In many cases it was found that the criticality of a given system failure mode was not necessarily determined by the mission phase or flight conditions in which the failure occurred, but by subsequent conditions. Many failure modes are relatively noncritical in high altitude cruise, for instance, but leave the system in a degraded state that may have a much greater criticality in subsequent mission phases such as low level penetration or landing. Since high altitude cruise accounts for a large portion of the mission duration, most of the failures will tend to occur during cruise, but many of the resulting aircraft losses will occur during a subsequent mission phase. For other failure modes, the surprise factor is predominant; the probability of aircraft loss is chiefly dependent on the pilot's skill and corrective actions immediately after the failure. These considerations were taken into account in the computerized program.

BITE

The system includes BITE (Built-In Test Equipment) which serves two main purposes:

a. It permits a quick preflight checkout to determine, as far as practicable, that all components in all channels are unfailed before takeoff.

b. It facilitates diagnosis by identifying the failed LRU.

Neither of the above BITE functions is achieved with 100 percent certainty. A careful analysis was made to determine which failure modes of which components could not be detected by BITE or by any feasible preflight check. For each such "hidden" failure mode, suitable ground check intervals were established. Whereever a hidden mode, in combination with other component failure modes, could produce a potentially critical system failure mode, the computation of the probability of system failure mode occurrence was based on the established ground check interval and not merely the time since takeoff. This makes a significant difference in the probability of a given two-failure or three-failure combination, as compared to the conventional method of computing redundant system reliability, which is based on the implicit assumption that all parts are unfailed at takeoff.

SNEAK FAILURE MODES

In addition to this "hidden" failure mode problem, we also encountered several "sneak" failure modes. A sneak failure mode may be roughly defined as one which produces unexpected effects that tend to negate part of the redundancy. Such modes exist chiefly because of inadequate FMEA (Failure Mode and Effect Analysis). For example, the voters used in the prototype design contained two sneak failure modes. In one of them, a single voter fault would produce a hardover signal on all three channels simultaneously. In the other, a single voter fault would cause a single hardover originating upstream to be propagated downstream on all three channels. These problems were corrected in the production design.

Another fertile field in which sneak failure modes typically abound is in the area of electronic module power supplies. Naturally, the three-channel redundant configuration of the electronics and sensors employed separate power supply modules to power the electronics on each channel. Here again sneak failure modes were found. For example, one power supply module failure could disable a channel and at the same time prevent the logic circuitry from taking proper action. Such modes were "designed out" wherever they appeared.

FAILURE MODE AND EFFECT ANALYSIS

As might be suspected from the above remarks, the task of analyzing failure modes and their effects was of paramount importance in making a realistic flight safety reliability analysis for the SAS. The FMEA is a traditional task that is usually called for in reliability programs, but the output, in many cases, is of little value in realistic computation of the reliability of a redundant system. Among the typical shortcomings are:

a. Excessive emphasis on <u>what</u> fails rather than <u>how</u> it fails; insufficient recognition of failure modes other than open circuit and short circuit.

b. Inadequate definition of effects on the system; use of catch-all phrases such as "loss or degradation of output"; phrases such as "Loss of +5 VDC power" without any attempt to describe what happens to the system when the +5 VDC power is lost.

c. Endless repetition of the obvious and neglect of the nonobvious.

d. Failure to explain the functioning of the system or assembly and its components so that the FMEA will be meaningful to personnel not highly familiar with the design.

e. Inadequate explanation of redundancies, where applicable; failure to recognize that while two assemblies may be in parallel with respect to the more common or obvious failure modes, they may be effectively in series with respect to less obvious failure modes.

Although formal FMEA reports at the assembly level were generated in the SAS reliability program, there was no attempt to compile a system-level FMEA in the usual format which is not well suited for delineating the effects of redundancies. Instead, the FMEA was effectively combined with the quantitative flight safety reliability analysis as illustrated by Figures 4 and 5. These figures represent two of the system failure modes. The notations f_{49}, f_{70}, etc. represent hourly failure rates of the various subassemblies in the applicable subassembly failure modes. In other words, they represent blocks on a series-parallel block diagram or a fault tree. Each critical system failure mode has a separate diagram or a separate branch on a fault tree, with blocks representing only those failure modes of subassemblies or components that contribute to the given critical system failure mode. Notations such as h_{71}, g_{67}, etc. are the applicable mode failure rates of subassemblies in an off-line or standby status. W represents the probability of icing conditions that would incapacitate a pitot head with a failed heater. The symbol H refers to the 300-hour periodic check for pitot system leakage, which is the failure mode denoted by f_{81}. The notations T_1 and T_2 refer to time since takeoff; for example, if a mission phase starts 5.52 hours after takeoff and ends 7.52 hours after takeoff, $T_1 = 5.52$ and $T_2 = 7.52$. Insofar as potentially critical modes are concerned, the FMEA is thus represented by a collection of critical system failure mode formulations similar to Figures 4 and 5. We have attempted the task of modifying the usual FMEA format to make it useful in redundant system analysis, but are not satisfied with results to date.

Many component failure modes were simulated in laboratory tests, in order to evaluate failure mode effects that were not clearly predictable.

BLOCK DIAGRAMS AND FAULT TREES

Series-parallel block diagrams and fault trees are sometimes thought of as two different techniques for redundant system reliability analysis, although when properly used they convey identical information. The chief differences between these two approaches, as traditionally used, are:

a. Blocks on the fault tree generally represent events or specific failure modes of components, while blocks on the series-parallel diagram have sometimes been used to represent the total failure rates of components.

b. The fault tree is generally constructed beginning at the top or system level and working down to the detail or functional module level; with the block diagram, there is a tendency to start at the component level and work up to the system level.

In the B-52 SAS analysis, we used two teams, one starting at the top and working down, and the other starting at the bottom and working upward. Comparison of the results provided a useful cross-check and helped to minimize the chance of overlooking critical combinations. As long as the blocks represent specific failure modes of the modules or components, there is no significant difference between the two diagramming techniques, and the choice between them is reduced to a matter of personal preference.

RELIABILITY TESTS

The reliability programs for both the prototype and production contracts included extensive system reliability testing in general accordance with MIL-STD-781. Ordinarily, system reliability tests are conducted primarily for the purpose of MTBF measurement or verification of compliance with MTBF requirements. For the SAS, the system tests were regarded primarily as opportunities for failure cause analysis in order that corrective actions could be initiated at the earliest possible date. It is almost axiomatic in the industry that the first MTBF test will show an MTBF of about one tenth of the predicted value. (Maybe we were just lucky; our first prototype MTBF test on the SAS indicated an MTBF of about one fourth of the prediction, instead of one tenth.) Most of the failures in the MTBF tests, as well as in the flight test program and operational mockup ("Iron Bird") tests, showed clear causes in a careful failure analysis, and corrective actions were initiated for the subsequent production articles.

MTBF testing under the production contract was divided into four phases:

Phase A consisted of about 1800 hours of operation on an incomplete system - partly with prototype hardware and partly with early production (unqualified) hardware.

Phase B involved 2000 hours of operation on early production hardware.

Phases C and D involved 515 hours each, using fully qualified production hardware.

The purposes of Phases A and B was to determine where reliability improvements were needed, at the earliest practicable date. The purpose of Phases C and D was to demonstrate attainment of the required MTBF.

The reliability test environments, both prototype and production, included cold soaks and operation at ambient temperatures up to 71°C (160°F). Initially, the prototype test included periods of applied vibration at 33 Hz and 2g amplitude. Vibration attempts were finally abandoned for the following reasons:

a. This low frequency was not found to produce any significant effects on equipment failure rates.

b. This type of vibration bears practically no relation to the vibration encountered in jet aircraft.

c. Any significant increase in frequency would require a totally new test setup. The supporting jig was marginal even at 33 Hz.

EFFECTS OF WEAROUT

It is widely assumed that scheduled replacements in service will avoid the occurrence of normal wearout failures. MTBF is consequently often considered as a function of random failure rates only; and since MTBF is customarily demonstrated by tests that typically operate each specimen for 500 hours or less, normal wearout is seldom significant in MTBF demonstrations. As a result, we see so-called MTBF values of 10,000 or even 50,000 hours quoted for mechanical and hydraulic equipment items, based only on their "random" failure rates under the assumption that scheduled replacement will avoid normal wearout problems.

MTBF in service, however, is a distinctly different problem. Scheduled replacements are seldom specified or practiced except where there is a clear-cut safety implication. As a result, the effective MTBF on such equipment is often far less than a pure "random failure" consideration would indicate.

SERVICE EXPERIENCE

For this reason, we kept two sets of books on the SAS MTBF -- one set based on random failure rates only, and the other including estimated normal wearout effects. Table I shows the resulting difference in predicted system MTBF, and also shows the failure experience in service for calendar years 1972 and 1973. The following conclusions may be noted from this table:

a. The hydraulics subsystem shows a distinct rise in failure rates from 1972 to 1973. The 1973 rates agree closely with the prediction that includes wearout effects.

b. The sensor-electronics subsystem shows a decrease in failure rates from 1972 to 1973, in spite of expected wearout effects in the six gyros. This indicates a mixture of two different kinds of apparent infant mortality effects:

    (1) The usual infant mortality experienced in electronic equipment, in spite of burn-in prior to delivery.

    (2) An improvement in the maintenance organizations' familiarity with the equipment, resulting in better repairs and fewer unnecessary replacements.

c. Field experience on the system as a whole agrees closely with the prediction that included estimated effects of normal wearout.

The last two columns at the right of Table I are based on detailed analysis of two field data samples which both indicated that about one third of the reported electronic failures might be attributed to trial-and-error troubleshooting or other diagnostic errors. This situation is believed to be improving with time and experience gained in the field.

Table II shows the various types of mission reliabilities experienced in service in the 1972-1973 period. There were no corresponding quantitative requirements or predictions.

Table III shows the SAS flight safety reliability requirements and predictions. The predictions were calculated both with and without normal wearout effects. There have been no losses to date attributable to the SAS. There were several early occasions of loss of one hydraulic power supply in service, due to fatigue failures of main pump rigid discharge lines which happened to be in resonance with the pump pulsation frequency. Actually, a similar failure had previously occurred in system reliability testing, but no importance was attached to it, since the test chamber space limitations required the use of plumbing configurations somewhat different from those of the aircraft. The lesson learned from this experience is that every effort should be made to use aircraft plumbing configurations in system reliability tests, particularly where there are conceivable resonance or fatigue problems.

The system MTBF tests indicated surprisingly low reliability for certain simple widely used standard or semistandard hydraulic components such as accumulators and pressure switches. Although corrective actions were initiated, the field reliability experience on these components is still disappointing.

CONCLUDING REMARKS

The next few years will see extensive development of electronic-hydraulic flight control systems of fly-by-wire and controls-configured-vehicle types, performing highly essential functions and with extremely high reliability requirements. The B-52 SAS program has provided useful experience for the development of such systems, and has demonstrated the need for close attention to the following considerations:

- Optimization of redundancy management.
- Meaningful Failure Mode/Effects analyses with particular emphasis on effects of redundancy and redundancy management and on early detection of possible sneak failure modes. References 1, 2, and 3 all provide useful guides for failure mode effect analysis.
- Laboratory simulation of failure modes to verify effects and serve as an added guard against sneak failure mode effects.
- Piloted simulator programs to measure pilot reaction to failure modes where applicable, under various visibility and turbulence conditions.
- Adequate consideration of wearout effects in mechanical/hydraulic components.
- Quantification of system failure mode criticalities to permit better allocation of effort and redundancy.
- Adequate BITE to avoid takeoff with possible hidden failure modes.
- Suitable periodic checks for detection of possible hidden failure modes not feasibly detectable by BITE.
- Proper reflection of periodic check interval in reliability predictions, for modes not detected by BITE.
- Adequate BITE fault isolation capability to facilitate proper system repair.
- Definition of reliability requirements for supplier-designed components

in terms of failure mode effects and redundancy management as well as the customary MTBF requirements.

- Establishment of schedule that permits adequate reliability testing to find areas for reliability improvement at earliest possible time before final design freeze.

- Vigorous failure analysis and reliability corrective action program, not only in reliability tests but also in other test areas (qualification, iron bird, flight tests, etc.)

REFERENCES

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2. Crown, Peter L.: Design Effective Failure Mode and Effect Analysis. Proceedings, 1969 Annual Symposium on Reliability, Chicago, January 1969.

3. Greene, K., and Cunningham, T. J.: Failure Mode, Effects, and Criticality Analysis. Proceedings, 1968 Annual Symposium on Reliability, Boston, January 1968.

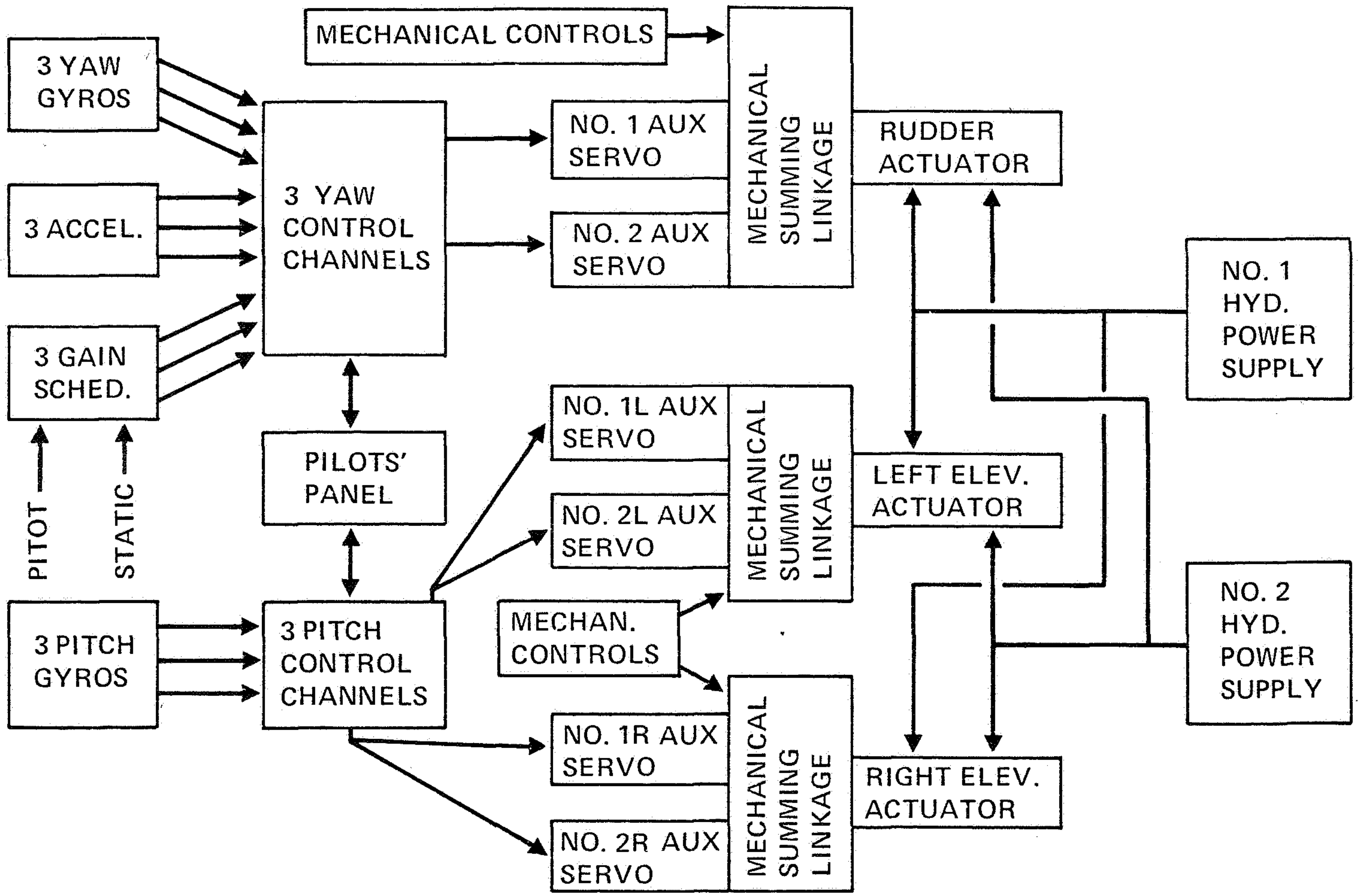

Figure 1. - B-52 SAS Diagram.

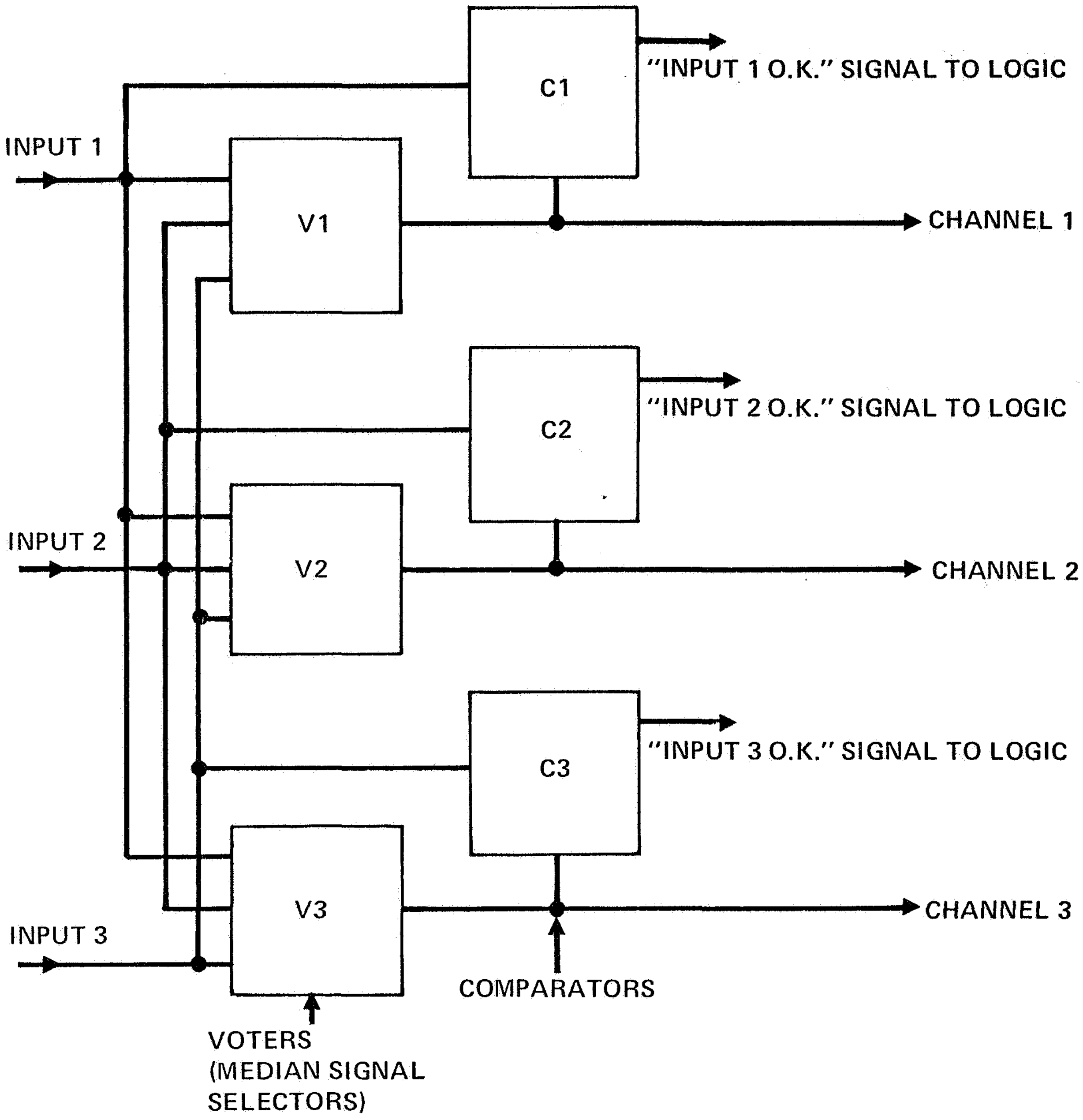

Figure 2. - Typical Voter-Comparator Diagram.

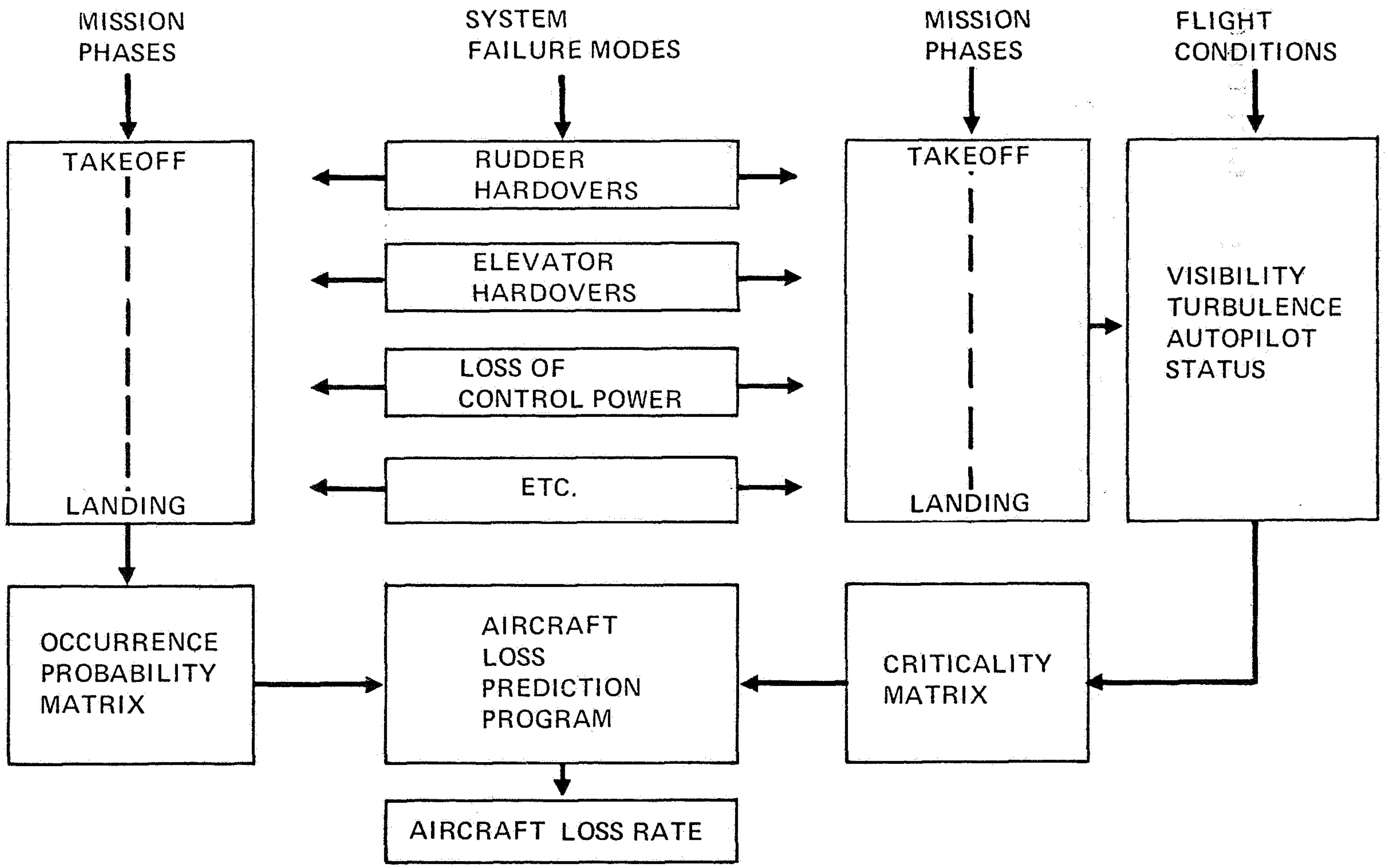

Figure 3. - Matrices and Loss Predictions.

MODE 25. MOMENTARY RUDDER HARDOVER TO SAS AUTHORITY LIMIT OR LESS, CUT OFF BY PROMPT COMPARATOR TRIP PRODUCING LOSS OF YAW DAMPING.

CONDITIONS PRODUCING MODE 25 ARE:

ITEM	PROBABILITY
(1) OPEN LOOPS ON BOTH SERVO CHANNELS (EITHER SEQUENCE)	$(f_{49} + f_{70} + f_{87})\,(f_{50} + h_{71} + f_{87})\quad (T_2^2 - T_1^2)$
(2) FAILURE OF NO. 1 SERVO CHANNEL (ANY SOURCE OF COMPARATOR TRIP OTHER THAN OPEN LOOP), FOLLOWED BY OPEN LOOP ON NO. 2 SERVO CHANNEL	$(1/2)\,(f_{28} + f_{40} + f_{45} + f_{47} + 2f_{60} + f_{66} + f_{68} + 2f_{86} + f_{88} + f_{89})\,(f_{50} + f_{71} + f_{87})\quad (T_2^2 - T_1^2)$
(3) FAILURE OF NO. 2 SERVO CHANNEL (ANY SOURCE OF COMPARATOR TRIP OTHER THAN OPEN LOOP), FOLLOWED BY OPEN LOOP ON NO. 1 SERVO CHANNEL	$(1/2)\,(f_{28} + f_{44} + f_{46} + f_{48} + f_{60} + g_{67} + g_{69} + f_{86} + f_{88} + f_{89})\,(f_{49} + f_{70} + f_{87})\quad (T_2^2 - T_1^2)$

P_{25} = PROBABILITY OF OCCURENCE OF MODE 25 BETWEEN T_1 AND T_2

$$= \Big[\{f_{49} + f_{70} + f_{87}\}\,\{f_{50} + h_{71} + f_{87} + (1/2)\,(f_{28} + f_{44} + f_{46} + f_{48} + f_{60} + g_{67} + g_{69} + f_{86} + f_{88} + f_{89})\} + (1/2)\,(f_{28} + f_{40} + f_{45} + f_{47} + 2f_{60} + f_{66} + f_{68} + 2f_{86} + f_{88} + f_{89})\,(f_{50} + f_{71} + f_{87})\Big]\ \big[T_2^2 - T_1^2\big]$$

Figure 4

MODE 33: SUSTAINED RUDDER OSCILLATION (FLUTTER) AT AIRSPEED ABOVE 300 KNOTS EAS, DUE TO EXCESSIVE YAW SAS GAIN.

CONDITIONS PRODUCING MODE 33 ARE:

ITEM	PROBABILITY
(1) LOSS OF PITOT PRESSURE:	
(1a) FAILURE OF BOTH PITOT HEATERS, MULTIPLIED BY PROBABILITY OF MODERATE TO SEVERE ICING CONDITIONS	$(f_{80})^2 (W) (T_2^2 - T_1^2)$
(1b) FAILURE OF EITHER PITOT HEATER (MULTIPLIED BY PROBABILITY OF ICING), AND LARGE LEAK IN OPPOSITE PITOT LINE	$2W(f_{80}) (f_{81}) (\overset{*}{300}/2)\ T_2 - T_1)$
(1c) LARGE LEAKS ON BOTH PITOT LINES	$(f_{81})^2 (\overset{*}{300}) (T_2 - T_1)$
(1d) SINGLE FAILURE IN PITOT MANIFOLD VALVE, PSU MANIFOLD OR INTERCONNECTING HOSE	$f_{82} (T_2 - T_1)$
(2) DEGRADATION OF PSD GAIN IN YAW SERVO POSITION FEEDBACK LOOP	$f_{83} (T_2 - T_1)$
(3) STUCK SOLENOID VALVE ON NO. 1 YAW SERVO, COMBINED WITH ANY TRIP OF NO. 1 SERVO COMPARATOR WHICH LEAVES SENSOR COMMAND APPLIED TO SERVO	$(f_{90}) (f_{40}+f_{60}+f_{86}+f_{88}+f_{89}) (T_2^2 - T_1^2)$

P_{33} = PROBABILITY OF OCCURRENCE OF MODE 33 BETWEEN T_1 AND T_2

$$= (f_{80})^2 (W)(T_2^2 - T_1^2) + W(f_{80})(f_{81}) (\overset{*}{300})(T_2 - T_1) + (f_{81})^2 (\overset{*}{300}) (T_2 - T_1) + f_{82}(T_2 - T_1)$$

$$+ f_{83}(T_2 - T_1) + (f_{90}) (f_{40} + f_{60} + f_{86} + f_{88} + f_{89}) (T_2^2 - T_1^2)$$

*H = 300 HOURS FOR f_{81}

Figure 5

TABLE I

MTBF COMPARISONS

ITEM	FAILURES PER THOUSAND FLIGHT HOURS					
	PREDICTIONS BASED ON TEST EXPERIENCE		AFM-66-1 SERVICE DATA			
	NO WEAROUT	WITH WEAROUT	COUNTING ALL REPORTED ELECTRONIC FAILURES		COUNTING 2/3 OF REPORTED ELECTRONIC FAILURES	
			1972	1973	1972	1973
SENSOR/ELECTRONICS SUBSYSTEM	5.077	7.459	9.756	8.705	6.504	5.803
HYDRAULICS	2.553	7.271	5.306	7.564	5.306	7.564
MISCELLANEOUS	1.697	1.697	0.601	0.857	0.601	0.857
SYSTEM	9.327	16.427	15.663	17.126	12.411	14.224
MTBF, HOURS	107	61	64	58	81	70
MTBF GOAL	100	—	—	—	—	—

TABLE II

SAS MISSION RELIABILITY COMPARISONS

BASIS: SAC AIR VEHICLE PERFORMANCE REPORTS, 1972 AND 1973

ITEM	RELIABILITY
FLIGHT RELIABILITY:	
PROBABILITY OF NO FLIGHT ABORT DUE TO SAS	99.96%
PROBABILITY OF NO SAS FLIGHT ABORT OR MAJOR DEGRADATION* IN FLIGHT	99.58%
DISPATCH RELIABILITY:	
PROBABILITY OF NO LATE TAKEOFF OR CANCELLATION DUE TO SAS	99.73%
COMBINED RELIABILITY:	
PROBABILITY OF NO SAS FLIGHT ABORT, MAJOR DEGRADATION, LATE TAKEOFF, OR CANCELLATION	99.31%

*INCLUDES LOSS OF PRESSURE FROM ANY OF THE FOUR PUMPS.

TABLE III

SAS FLIGHT SAFETY RELIABILITY

	FLIGHT SAFETY RELIABILITY	AIRCRAFT LOSS RATE DUE TO SAS, PER 10^6 FLIGHTS
GOAL	99.999182%	8.18
PREDICTION (NO WEAROUT)	99.999798%	2.02
PREDICTION (WITH WEAROUT)	99.999508%	4.92
EXPERIENCE TO DATE	NO LOSSES	NO LOSSES

C-9