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DESIGN, DEVELOPMENT, AND FABRICATION OF A CRASH SENSOR FOR MILITARY HELICOPTERS

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This effort resulted in the design and construction of a crash sensing system for military helicopters to be used to electrically detonate the squibs of an inflatable body and head restraint system (IBAHRS) during a crash. Calibration sensitivity levels were established through computer simulations using acceleration data collected in previous helicopter crash tests. The sensor system is sensitive enough to deploy the IBAHRS in time for it to be effective but not so sensitive that inadver-

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) tent firings occur due to expected acceleration levels of flight maneuvers, vibrations, and landings. The system was designed incorporating two independent sensors and an electronic diagnostic circuit which warns of system malfunction. The circuit also stores enough energy to fire the squibs. Six systems were fabicated, one of which was given laboratory tests to demonstrate compliance with a preliminary performance and environmental specification also produced as part of this effort.

SUMMARY

INTRODUCTION

Prior to the start of the work reported here, the Naval Air Development Center (NADC) spent considerable effort proving the feasibility and effectiveness of an inflatable body and head restraint system (IBAHRS). The IBAHRS consists of a conventional restraint system to which a pyrotechnically ignited gas generator and load distributing bladders have been added. The pyrotechnic is fired electrically by closure of the contact of an acceleration sensor which detects a crash. NADC's work reported by Schulman and McElhenney [1] used a standard light aircraft emergency locator beacon acceleration sensor for sensing the crash.

Although the sensor performed satisfactorily, it was by no means optimized to the crash characteristics of military helicopters. Such optimization involves the choice of sensor location, the determination of the required time to fire for effective IBAHRS protection, and the prevention of inadvertent actuations arising from hard landings, weapons firing or vibration.

Neither did the sensor respond omnidirectionally since it had a cosine response about its sensitive axis. Thus, it was not capable of sensing the variety of angle crashes common in helicopters.

Finally, to make the IBAHRS reliable, some type of redundant power source and self-checking and diagnostic features are necessary. Such circuitry is common in automotive air bag restraint systems.

This report describes the design and preliminary development of a sensor system which addresses the deficiencies in the sensor originally used for IBAHRS deployment. The methodology used, the resulting design and the testing performed are described. Plans for areas of improvement are presented.

SUMMARY OF RESULTS

The development of the crash sensor system was conducted in three phases. In the first phase, crash data in the form of acceleration histories were collected through a literature search, and then used in computer simulations to optimize the sensor system design. Calibration levels were determined which provided fast response, but which nevertheless are not so low as to allow inadvertent actuation. A single sensor location was chosen independent of the specific aircraft. Also included in the first phase was the preliminary design of the crash sensor system. For sensing acceleration in the vertical direction a gas damped piston in tube was chosen. An omnidirectional spring-mass sensor was chosen for acceleration sensing in the horizontal plane. The supporting circuitry including the redundant power source and the diagnostic capability were also designed.

During the second phase the detailed design of the sensors and the diagnostic circuit was done along with the integration of thse subsystems and the packaging of the entire unit. A prototype system was built and tested according to a preliminary specification [2] written on the basis of the performance requirements determined in the first phase and a knowledge of military helicopter operational environments. The test unit performed satisfactorily during and following the tests. The results are documented in [3].

After the testing was completed, new information relative to the advanced attack helicopter (AAH) became available which necessitated changes to the specification to accomodate unusually high g maneuvers.

The second phase also included the preparation of a complete set of detailed drawings [4] and a failure mode effects and criticality analysis (FMECA) [5]. The FMECA identified three categories of failure modes with exceptionally high overall risk priority indices. These categories are failure modes arising from plating, contamination and loose parts. Inspection techniques which can be implemented in large volume production were proposed to increase the likelihood of detection of these problems, thereby reducing their overall risk priority indices to acceptable levels.

Phase three was primarily concerned with the construction of five deliverable systems. At the beginning of phase three, the new information about the AAH maneuvers and vibration levels was reviewed carefully. The vibration levels are much lower than those used in the original preparation of the preliminary specification. The high g maneuver necessitated a change in the calibration level of the vertical sensor. During construction, three systems were built with the vertical sensor calibration level set for use in the AAH. The other two systems were calibrated as originally specified. All five systems were required to meet only the revised vibration specification. All five systems were given a series of acceptance tests and all five performed satisfactorily. The systems were delivered to NADC for laboratory and flight test use.

CONCLUSION

On the basis of available crash data and helicopter environments, a crash sensing system capable of providing effective discrimination between crash and non-crash events can be produced. Such a system can be made reliable and self-diagnostic.

RECOMMENDATIONS

1. Further testing using the five systems built in the third phase should be done by the Government to verify the calibration level of both the regular and AAH calibrations in one or more actual helicopter drop tests and verify the insensitivity to vibration levels in actual flight conditions.

2. The preliminary specification should be reviewed by the Government with an eye toward reducing the severity of the environments specified. The specification currently is at least as stringent as it need be. In particular, the requirement for operation at -55°C increases the size and weight of the system considerably.

3. Engineering development should be continued to refine the design and develop tooling to accomplish:

- An overall reduction in size and weight.
- An adequate environmental seal of the system.
- A scheme for internal modular assembly allowing the field replacement of parts.
- A method of increasing the ruggedness of the mountings of the internal parts.

4. The diagnostic circuitry should be redesigned so that it not only indicates a failure with its warning lamp but also provides a means for determining, in the field, the defective component. Micro-processor diagnostic systems which do this are currently in use in automotive air bag systems and should be used as models for the design of the helicopter crash sensing system diagnostic.

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BACKGROUND

The process of optimization of a crash sensing system for any given application is many faceted. During the design process, consideration must be given simultaneously to factors including the choice of sensor type and location in the aircraft and the ability to reliably detect a crash in time for the sensor to be effective while maintaining adequate rejection of non-crash events. Also, the performance of the chosen sensors must not be so sensitive to manufacturing tolerances that they cost too much.

A series of computer simulation programs are employed which allow the design engineer to interactively couple his sensor experience with computer predicted sensor performance in as many crash events as possible for which acceleration data is available.

The process begins with the collection of crash data. These data are entered into the computer to verify their accuracy. For each crash event, the required sensor response time is then obtained from actual occupant motion or, if unavailable, from simulated dummy kinematics. Given the collection of response times for all crashes, the sensor designer then considers a variety of sensor types and locations and can quickly reject those which show little promise. For those remaining, he can then modify their parameters to achieve optimum response to crash signatures. This same variation of parameters also highlights those designs which are the least acceptable to manufacturing tolerances. Armed with the knowledge of the performance characteristics of a limited number of sensor designs, the engineer can then intelligently select the best for subsequent detailed design and development.

CRASH SENSOR TYPE EVALUATION

Eight generic sensor types, three predictive and five post impact, were evaluated and rated with respect to nine factors. Weights for the nine factors were determined and were used to calculate weighted totals for the eight sensors. The ratings, weights, and totals are presented in Table I.

The generic sensor types chosen for evaluation are those which have been used in crash sensing systems for aircraft and automobiles. Three predictive sensor types considered were radar, sonar, and proximity. Post impact types included four mechanical types, rolamite, spring mass, gas damped piston in tube, and crush sensors. The non-mechanical post impact type was one in which the output of an accelerometer is processed electronically.

The most important evaluation factors were response time, inadvertent actuation susceptibility, environmental stability, reliability, weight and serviceability. Of secondary importance

Table I

Sensor Type Evaluation Matrix

Attribute	Weight	Radar	Sonar	Proximity	Electronic	Rolamite	Spring-Mass	Gas Damped	Crush
Response Time	.12	10	10	8	6	5	5	6	4
Inadvertent Susceptibility	.17	5	3	6	8	7	9	10	4
Environmental Stability	.12	4	4	4	8	8	9	9	10
Operational History	.07	3	1	1	8	10	8	10	8
Cost	.04	1	1	2	3	8	10	9	6
Reliability	.12	3	2	1	7	8	9	9	6
Complexity	.09	2	2	2	3	7	9	8	10
Weight	.14	2	2	4	8	8	7	9	6
Serviceability	.13	3	2	1	10	9	10	10	8
Weighted Totals		3.99	3.26	3.60	7.25	7.65	8.34	8.92	6.66

Rating: 10 best; 1 worst; maximum score 10.

were operational history, cost and complexity.

Clearly, predictive sensor types are faster than post impact types. Since they would be able to detect an impending crash prior to any structural deformation, and since helicopter structures are large, it would likely be necessary to build in a time delay which could be different for each helicopter type. The squib firing would have to be delayed by some amount so that the harness would not begin to deflate before maximum force loading on the harness occurred.

The post impact sensor types are less sensitive to inadvertent actuations and environmental changes than the predictive types. This is because they require physical contact of the aircraft structure and thus cannot be misled by rain, birds, and other airborne projectiles.

Primarily because of their simplicity, post impact types are less costly, more reliable, lower in weight, and easier to service. The electronic sensor type suffers in some of these respects, but not nearly so much as the predictive sensors.

The three predictive sensors stand out as having the lowest ratings. It is therefore not surprising that part of their poor showing was due to a lack of operational history. They have been sudied in the laboratory and have rarely been chosen as the design for implementation.

Two sensor types, spring mass and gas damped, score highly, with the rolamite and electronic sensor not far behind. The crush sensor faired poorly, due in large part to the large number of individual sensors needed to adequately cover surfaces of impact. It was decided to investigate the rolamite, spring mass, and gas damped sensors, rejecting the electronic one because, in the likely event of multiple sensors (of possibly different types), it would be easy to combine mechanical types with each other and not with the electronic sensor.

CRASH DATA GATHERING, PREPARATION AND VERIFICATION

It was hoped that instrumented crashes for many different helicopter types and crash conditions would be found, along with hard landing and in-flight vibration data from which no-go criteria could be developed. The search was quite successful in finding a relatively large number of crashes and helicopter types. Several crash conditions were found, although most tended to be about 40 ft./sec. in horizontal and vertical velocity. The search did not turn up any no-go events.

Two avenues were pursued in the search for data--a computerized literature search, and telephone contacts with authors and others in helicopter testing and engineering. The result of the personal contacts and the computerized literature search ultimately led to the accumulation of about 25 documents containing pertinent information on 18 different instrumented helicopter crashes and several non-crash events of interest. A summary of this information is presented in Table II, with the list of references to the documents containing the data. Each crash event has been assigned an identifier (e.g. T-18) which corresponds to the identifier used by those who conducted the test. In two cases there was no identifier or it was not known. These events were called UT-1 and UT-2.

In general, the documents found in the literature search presented acceleration traces for several locations. Traces for the cockpit floor and often the passenger or cargo floor were digitized and entered into the computer. Traces for the engine, transmission, fuel cells, and other distant parts of the aircraft structure were not studied. The reasons for this were twofold. First, few of these structures would routinely be involved early enough in the crash to protect the crew, so that adequate coverage of these peripheral locations would require an unreasonably large number of sensors. The advantage of slightly earlier detection of the crash does not warrant the increased complexity and attendant reduction in reliability of a distributed sensor system. Second, simulations of the response of sensors in the crew area generally predict adequately fast response. In all, 64 data traces were digitized and used in our simulations.

In addition to spotting human errors introduced in the digitizing process, each data trace was integrated to find the velocity as a function of time. Integration of each acceleration history should yield a velocity equal to the "advertised" impact velocity in the direction. Very few data sets passed this test. Many real factors can cause this to happen, along with some which are just due to instrumentation problems. One real factor is the rotation of the accelerometer during the crash with respect to its intended direction. Since a crash sensor similarly located would have undergone the same rotation, such a data trace is valid. Experimentation problems include accelerometer breakage, wrong scale factors, and zero drift. Because many of the crash tests were 10 to 15 years old, it was no longer possible to discuss instrumentation errors with those who conducted the tests. Thus, it was decided to use all reasonable data traces with caution. Those which caused problems for the sensors would be scrutinized carefully.

DEVELOPMENT OF PERFORMANCE REQUIREMENTS

Computer simulation proceeded in a three-part process. First, the functional requirements for sensor response were determined by developing time-to-fire criteria and no-go criteria. Next, sensor parameter sets were generated which, when used in simulation with the no-go criteria and a variety of acceleration histories did an acceptable job of meeting the criteria for functional response. Finally, the effects of perturbations in the parameters were studied to help establish

Table II

Crash and Other Data Found in Literature Search

Crash Conditions

Crash I.D.	Reference	Helicopter Type	Vertical Velocity	Forward Velocity	Pitch	Roll	Yaw
T-1	[6]	H-25	45 ft/sec	35 ft/sec	0°	0°	0°
T-2	[6]	HUP-2	45	35	0	0	0
T-3	[6]	H-13	45	35	0	0	0
T-4	[6]	HUP-2	45	35	0	0	0
T-5	[6]	H-13	45	35	0	0	0
T-7	[7],[8],[9]	CH-21A	40	48	3 up	4 left	0
T-13	[10]	H-21A	40*	48*	3*up	4*left	0*
T-18	[11]	CH-21A	41	41	N/A	N/A	N/A
T-21	[12]	OH-4A	25	0	N/A	N/A	N/A
T-22	[12]	OH-4A	34	25.3	30 down	N/A	100° left
T-23	[13]	CH-34	43	41	0	0	0
T-25	[14]	OH-5A	25	0	0	0	0
T-34	[15]	UH-1D/H	29.9	0	$\frac{1}{2}$ down	0	2 right
T-38	[16]	UH-1D/H	23	18.6	N/A	N/A	N/A
T-39	[17]	CH-47C	39.54	29.8	10 up	1	0
T-40	[18]	CH-47A	43.5	28.3	8.7 down	0	0
UT-1	[19],[20]	H-25A	44	44	4 up	6 left	5 left
UT-2	[21]	UH-1D/H	42.4	30.4	0	26 left	0

Non-crash data of interest:

	Vertical Velocity	Forward Velocity	Pitch	Roll	Yaw
AAH predicted vertical crash pulse	50	--	--	--	--
Sled run A-79-046	--	61.6	--	--	--
Sled runs A-79-030, 036, 039	--	54.3	--	--	--
Sled run A79-032	--	42.5	--	--	--

*Not explicitly given in documentation. Given as similar to T-7.
N/A Not available

manufacturing tolerances and calibration criteria, and laboratory test parameters were found.

The best time-to-fire criteria come from actual occupant motions given by accelerometers near unrestrained dummies. If such data were available it would be possible to doubly integrate the acceleration histories to determine occupant motion as a function of time. Some limit could then be placed on the allowed motion prior to full inflation of the harness.

Generally, where dummy data are available, they are for dummies restrained in ways which vary from crash to crash. A way of using these data is to require full harness inflation by the time peak acceleration occurs at the dummy's head, chest, or pelvis. Thus, using the 20 millisecond inflation time for the IBAHRS, the required time to fire for a given crash would be 20 milliseconds prior to the earliest peak acceleration load given in the dummy data for the crash.

When dummy data are not available, another criterion must be used. Such a criterion is based on the motion of an unrestrained body near or at the mounting location of the sensor. Also required is that the occupant velocity at the time of initial contact with the restraint be within limits based on those used in automotive air bag specification. Analyses of this type led to the criterion that the sensor must fire no later than 20 milliseconds before an unrestrained body has moved 2½ inches. The use of this criterion in the absence of dummy data is conservative, since the actual accelerations of an occupant are often delayed by the collapse of intervening structures such as the seats. For crashes which had no available dummy data, this time-to-fire criterion was applied to their data sets using the computer. The resulting time-to-fire requirements are presented in Table III, which additionally shows whether the requirement came from dummy or calculation in the absence of such data.

It was hoped that accelerometer traces of non-crash events such as hard landings and in-flight vibration would be found. None were. The approach therefore became one of the devising no-go criteria from helicopter vibration specifications. Early in the second phase, the only vibration information was that in MIL-STD-810. Later on, actual AAH vibration information showed that the MIL-STD-810 levels were unrealistically severe for operating vibration. Non-operating vibration should still be that called out by MIL-STD-810. A revised operating vibration specification is depicted in Figure 11. The analysis which led to this curve is given in the Appendix.

LOCATION SELECTION

In automotive crash sensor systems the sensors are always mounted forward of the passenger compartment so as to detect the crash earlier. This is necessary because automotive struc-

TABLE III

Time to Fire Required

Crash I.D.	Reference	Page/Figure Reference	Time of Peak Dummy Load (msec)	Location	Required Time to Fire (msec)
T-1	[6]	Fig. 9	33	Pilot Pelvis Vert.	13
T-2	[6]	Fig. 9	38	Pilot Pelvis Vert.	18
T-3	[6]	Fig. 9	43	Pilot Pelvis Vert.	23
T-4	[6]	Fig. 9	58	Pilot Pelvis Vert.	38
T-5	[6]	Fig. 9	37	Pilot Pelvis Vert.	17
T-7	[7]	p. 21	160	Commercial Seat Passenger Pelvis Lat.	140
T-13	[10]	Fig. 4	--	Passenger Cabin Floor Vert	107*
T-18	[11]	Fig. 11	--	Passenger Fwd. Cabin Floor Long.	68*
T-21	[12]	p. 56	64	Pilot Pelvis Long.	44
T-22	[12]	p. 67	82	Pilot Pelvis Vert.	62
T-23	[13]	p. 17	--	Passenger Fwd. Cabin Floor Long.	11*
T-25	[14]	p. 32	83	Co-pilot Pelvis Long.	63
T-34	[15]	p. 133	--	Pilot Floor Vert.	38*
T-38	[16]	p. 166	107	Passenger Pelvis Vert.	87
T-39	[17]	p. 11	102	USAAVS FF Dummy Vert.	82
T-40	[18]	p. 55	48	Dummy Left Long.	28
UT-1	[19]	p. 52	96	Pilot Seat Belt R.H. Side Load	76
UT-2	[21]	p. 55	>130	Co-pilot Dummy Chest	>110
AAH	--	--	--	Theoretical Pulse	33*

* Computed: no dummy data available

tures are relatively stiff, allowing the crash to propagate quickly through the engine area to the occupants. This location is possible because automobile crashes generally come from the front.

In a helicopter, the likelihood of crashes from the side and bottom is comparable to that from the front. In order to achieve the fastest detection of a crash from all directions, it would be necessary to have many sensors installed around the body of the helicopter, a number of which would be relatively unprotected from accidental firings.

Furthermore, since the helicopter structure is quite soft and much larger than that of an automobile, the propagation of the crash from the exterior to the cockpit area is relatively slow. Thus, extremely rapid crash detection is not needed. Indeed, it might be undesirable because structure dependent time delays might have to be included.

If a distributed sensor system were to be used, simply the multiplicity of sensors would complicate the system, thus compromising its reliability. The diagnostic circuit would also become more complex.

In view of the above considerations, the approach was to attempt to design a sensor system whose sensors would be located in the cockpit itself. Such a system is not required to correlate acceleration in one part of the aircraft with later accelerations in the cockpit area, but instead, is measuring the primary signature--that acceleration from which the IBAHRS is to protect the crew.

By restricting the sensor location to the cockpit area, dependence on the exact nature of the aircraft structure is removed. Such a system should, therefore, work equally well in all helicopter types.

COMPUTER AIDED PRELIMINARY DESIGN

Three types of sensors were initially investigated--rolamite (unidirectional), spring mass (omnidirectional), and gas damped (unidirectional). The approach was to develop parameter sets which represented sensors that a) met or exceeded the time-to-fire requirements, b) would not actuate under vibration, and c) had parameters which were readily achievable in a real device with no great difficulties arising from manufacturing processes.

It was found that the rolamite sensor could not be configured to be fast enough to fire, while remaining safe under vibration. It is possible that with further refinements of the band force parameters, this sensor could be made to perform acceptably. However, it was felt that equal effort expended on the other two sensor types would yield even better performance. This belief, coupled with the high score for the spring mass and gas-damped devices relative to the rolamite (see Table I) led Technar to propose the omnidirectional sensor for crash detection in the horizontal plane and the gas damped sensor for the vertical direction. Figures 1 and 2 are schematic representations of the two chosen sensors.

The omnidirectional sensor is shown at rest in Figure 1. The cylindrical sensing mass is loaded downward against the base of the cone-shaped housing by the conical spring. Sufficient acceleration from any direction in the horizontal plane causes the mass to pivot at a point at the outer edge of its base. As the mass tilts, the protrusion from its base moves upward and loads the ribbed leaf less. At the firing angle, the normally closed contacts have already opened, and the normally open contacts just close. The contact gap is such that under vibration, causing the mass to move but not fire, the normally closed contacts remain closed. The mass can actually tilt through an angle greater than the firing angle. This overtravel allows an increase in the normally open contact force and decouples the mass from the ribbed leaf.

The gas damped sensor to be used to sense the vertical accelerations is shown at rest in Figure 2. Three compression springs are employed to achieve the necessary spring rate and contact closures. The net rate of the normally closed contact spring and bias spring determine the rate used in the model. The mass is initially held at the left against the central stop by a net force of 2 g's including the effect of gravity.

Acceleration causes the piston to move to the right (down), opening the normally closed contact spring at its free length shortly before the normally open contact spring bridges the contacts. The mass can overtravel by compressing the normally open contact spring until stopped by the central protrusion of the mass. The contact force thus goes up during overtravel.

As the piston moves, air is pumped both through the hole and around the circumference from the forward ullage to the aft ullage. The compression of the gas provides an additional spring rate as modeled with the computer.

The omnidirectional and gas damped parameter sets were used to simulate the performance of a system comprised of one of each type. This system, in which the omnidirectional spring mass sensor covers the horizontal plane and the gas damped device senses the vertical, would be located on the cockpit floor.

The object of the simulation was to predict whether or not the occupants would have been adequately protected in the various crashes listed in Table II. That is, would a system as described above function as fast or faster than the minimum time to fire for any occupant and any direction as tabulated

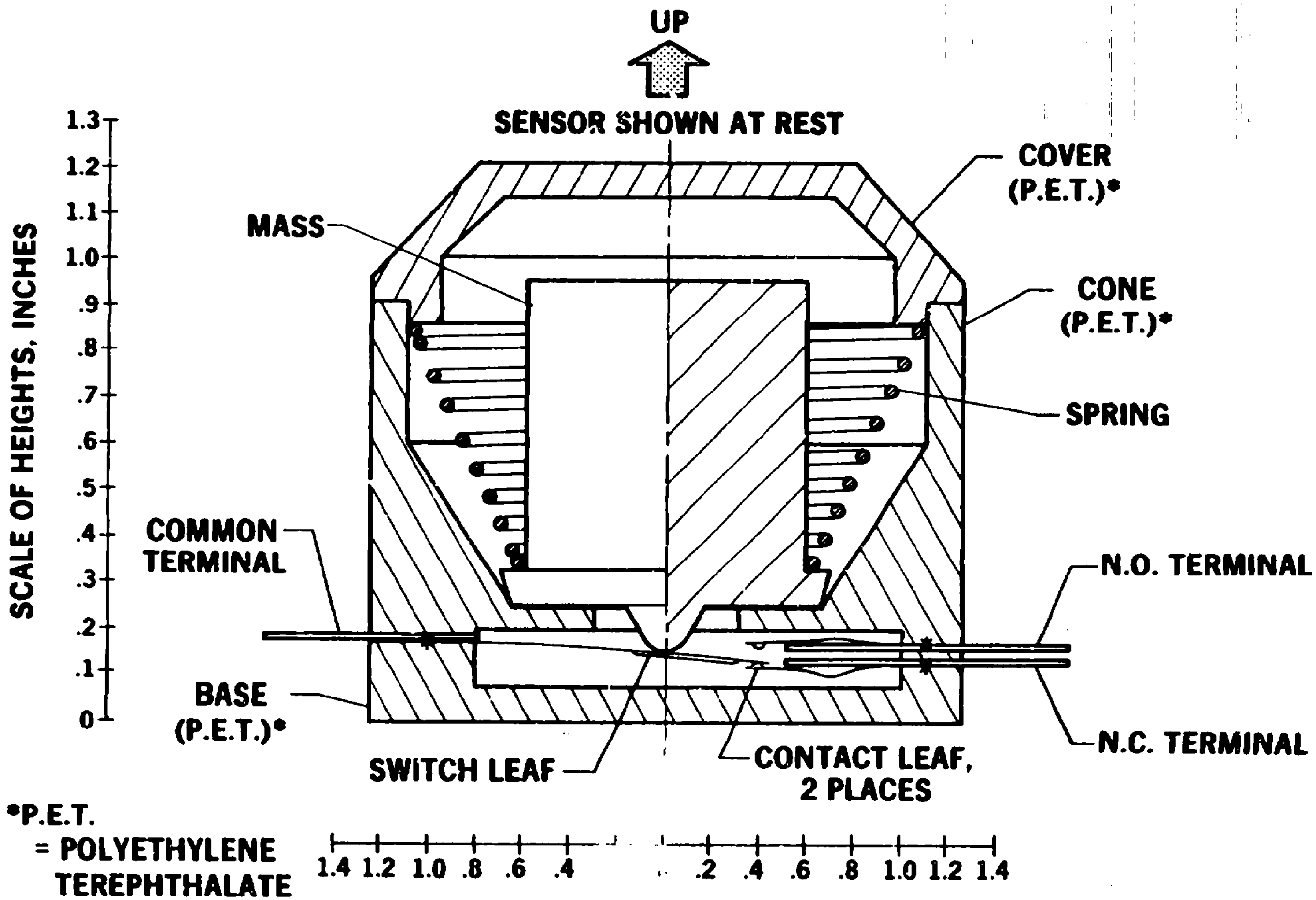


Figure 1 - Omnidirectional Spring Mass Sensor - General Arrangement

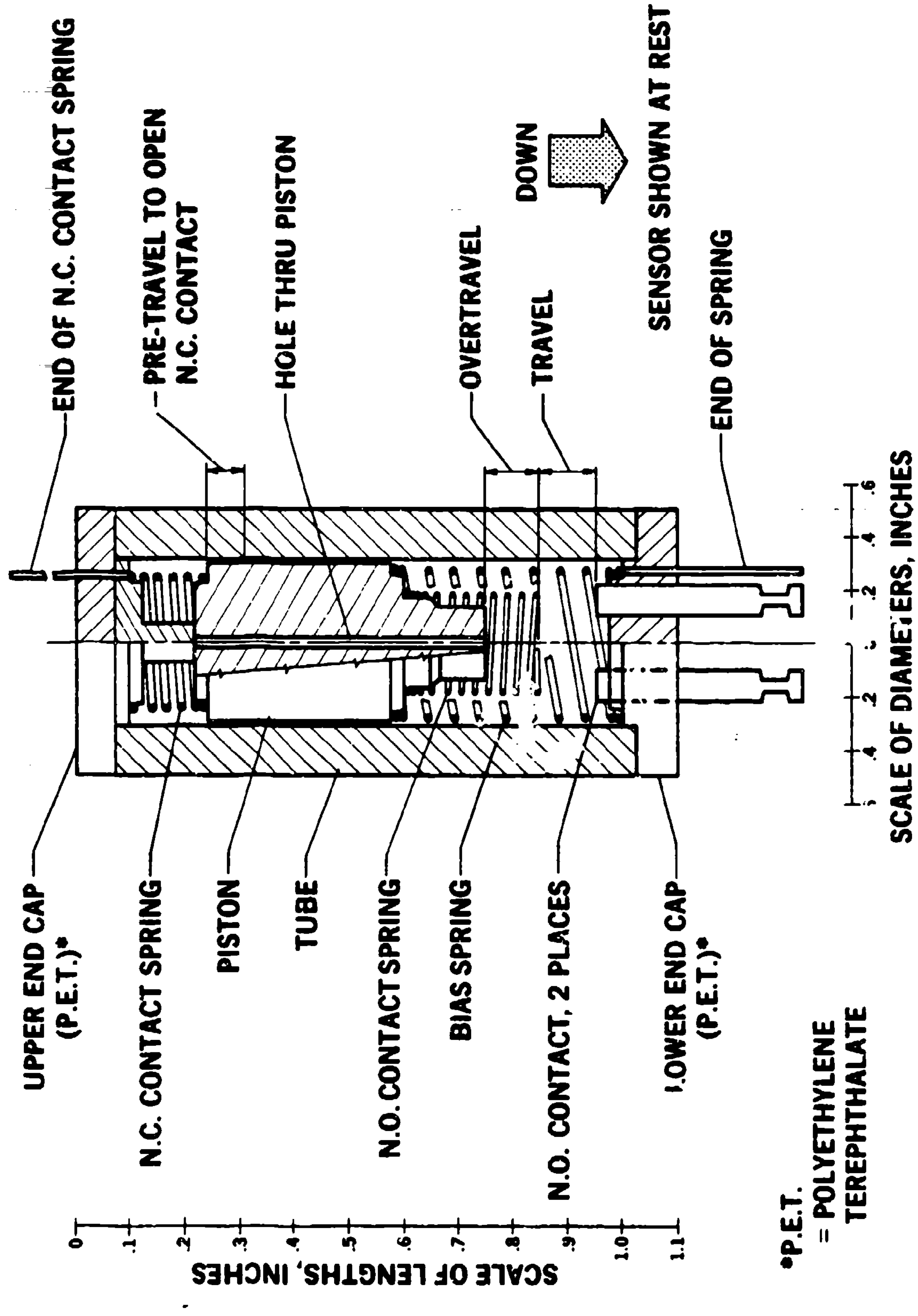


Figure 2
Gas Damped (Vertical) Sensor, IBAHRS Sensor System
Preliminary General Arrangement

in Table III? Table IV compares the required time to fire (from Table III) with the results of the simulations. Table IV also shows which of the two sensors would have fired the squibs.

Examining Table IV, the occupants of crashes T-1, T-22 and T-38 are marginally protected (1 to 2 msec late). This time lapse is within the expected accuracy of the simulations. Crashes T-23 and T-25 are about 6 to 7 msec late. In all the remaining crashes the occupants are comfortably protected.

Simulations for crash T-23 had to be based on the sensors being located with the passengers, since no cockpit data was available. Generally, cockpit response is faster than that for the passenger/cargo areas. Probably the 7 msec lateness would have been removed had cockpit data been available.

The time to fire required from crash T-25 came from a spike in the acceleration history of the copilot pelvis longitudinal axis. Other histories from the pilot, copilot, and passenger dummies show more significant peak loads from 5 to 10 milliseconds later. Thus, the proposed sensor system would likely protect all of the occupants to a large degree, particularly since there would have been partial inflation of the harness.

Some of the parameters for both sensors were selected to determine the effects on sensor performance due to their variation. Parameters not selected for this study were already known to be relatively unimportant. The amount of variation chosen for each one was such that ordinary manufacturing practices can be used to stay within the resulting tolerances.

The results of the study are presented in Table V. None of the variations in any of the parameters would be troublesome if it occurred alone. The most critical parameters are the piston-tube gap, the travel distance, and the initial force on the moving mass. No surprises were uncovered.

Looking ahead to laboratory testing of the prototypes to be constructed, a nominal threshold curve for each sensor was computed. Response to rectangular pulses was chosen because of a particular piece of test equipment at Technar. Response to other shapes can easily be produced. The threshold curves are shown in Figure 3. Sensor time to fire in milliseconds is given parenthetically.

A complete description of the design process highlighted above can be found in [22].

ELECTRICAL ENERGY STORAGE

To eliminate the possibility that the power supply is

Table IV

Comparison of Required Time to Fire
with Predicted Time to Fire from simulation

Crash I.D.	Required Time to fire (msec)	Simulated Time to Fire (msec)	Firing Sensor V = vertical H = omnidirectional
T-1	13	14	V
T-2	18	11	V
T-3	23	10	V
T-4	38	5	V
T-5	17	15	V
T-7	140	18	V
T-13	107	51	V
T-18	68	21	H
T-21	44	30	V
T-22	62	63	V
T-23	11	18	H
T-25	63	69	V
T-34	38	24	V
T-38	87	89	V
T-39	82	21	V
T-40	28	12	H
UT-1	76	22	V
UT-2	> 110	64	V
AAH	33	22	V

TABLE V

Variation of Parameters Results

Parameter	Magnitude of Change	Relative Change	Relative Change in Travel during vibration	Relative Change in TTF* High Level Crash Pulse	Relative Change in TTF* Medium Level Crash Pulse	Relative Change in TTF* Low Level Crash Pulse
GAS DAMPED SENSOR						
Firing Distance	.020 in.	20%	N/A	6.39%	5.85%	4.69%
Piston-Tube Clearance	.0005 in.	50%	2%	2%	2%	2%
Piston Hole Diameter	.001 in.	5%	2%	2%	2%	2%
Forward Ullage Length	.02 in.	6.7%	1%	1%	1%	1%
Aft Ullage Length	.01 in.	10%	1%	1%	1%	1%
Bias G Level	.2 g's	10%	12.5%	2%	2.70%	4.04%
Spring Rate	1 g/in.	10%	1%	1%	1%	1%
OMNIDIRECTIONAL SENSOR						
Firing Angle	1°	12%	N/A	3.08%	2.69%	2.00%
Spring Rate	.01 lbs/in.	10%	1%	1%	1%	1%
Spring Preload	.01 lbs.	10%	13.33%	2%	2%	2.86%
Pivot Radius	.01 in.	3%	3.33%	1%	1%	1%

*TTF = Time to Fire

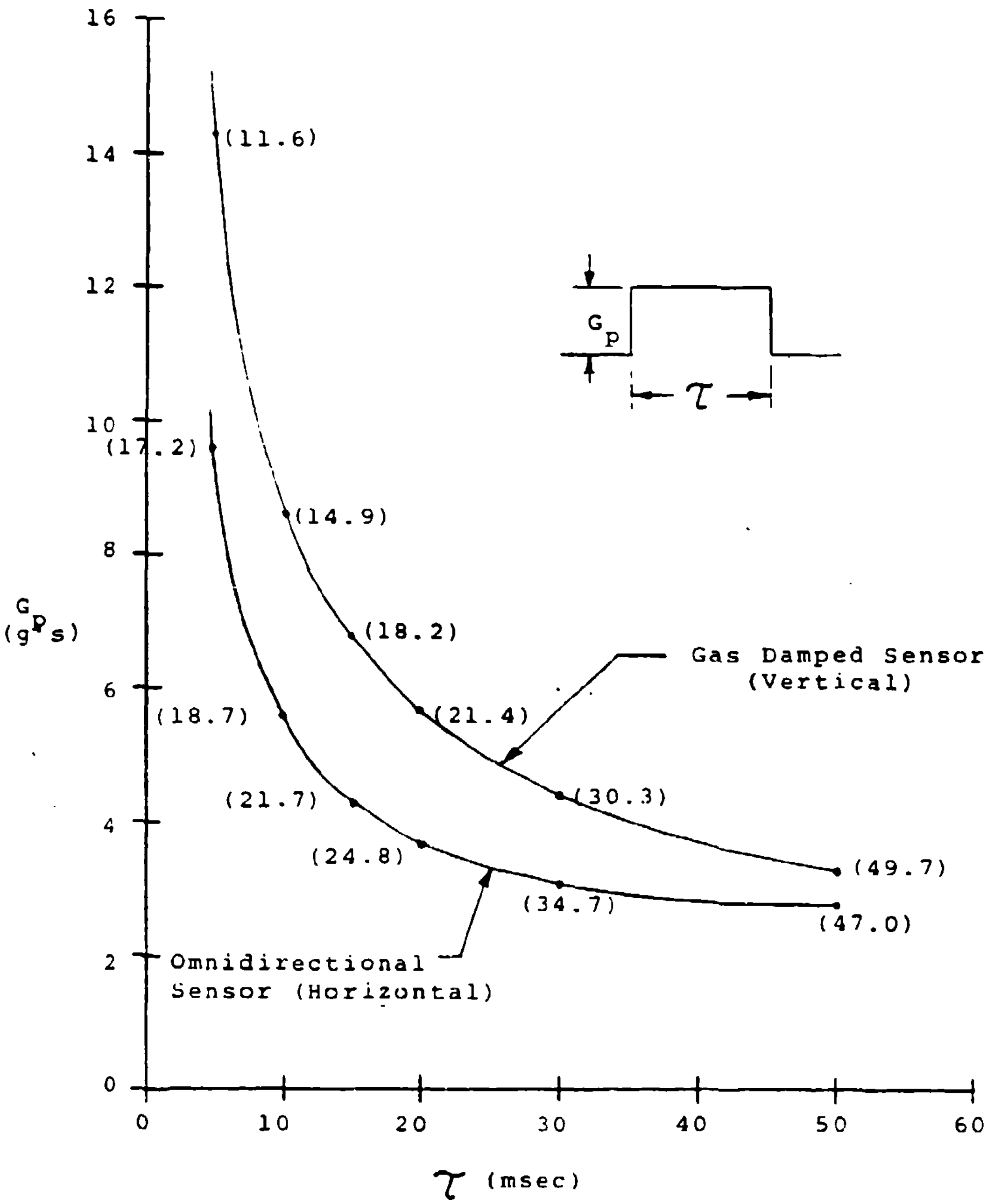


Figure 3 - Threshold Response of Sensors to Rectangular Pulses

interrupted during the crash, enough energy is stored in the sensor system's own capacitor to fire the harness squibs. This capacitor is charged by the aircraft power supply within a few seconds after power up. The size of the capacitor was determined by taking into account the aircraft power supply specifications, the environmental limits for the system, the energy needed to fire the squibs, parasitic series resistances, and tolerances on all parameters. The result was an 18,000 microfarad, 40 volt DC capacitor meeting MIL-C-39018.

DIAGNOSTIC DESIGN

The diagnostic circuit portion of the sensor system is used to verify that the entire system is working properly. It monitors the sensors, their secure mounting and the circuit itself, and provides an indication of any failure discovered. Diagnostic requirements were developed in part from Technar's automotive experience, from NADC requests, and from military aircraft electrical and environmental specifications. The preliminary design reulting from these requirements was constructed, and was found to operate nominally.

The diagnostic functional requirements are:

a) Must not degrade the reliability of the firing circuit.
b) Must provide a warning light indication of a system malfunction.
c) Must detect all single failures of sensors, interconnections, and as many components of the diagnostic circuit itself as possible.
d) Must detect power supply undervoltage.
e) Must be useable for multiple sensors.

The diagnostic environmental requirements include:

a)	MIL-STD-704	Aircraft Electric Power Characteristics
b)	MIL-STD-810	Environmental Test Methods
c)	MIL-STD-454	Standard General Requirements for Electronic Equipment
d)	MIL-E-5400	Military Specification Electronic Equipment, Airborne, General Specification for

The diagnostic circuit electrically integrates the sensor, the storage capacitor, and a mounting switch used to sense secure attachment of the sensor system to the airframe. The approach used to accomplish the diagnostic task was to provide each sensor with two resistors forming a voltage divider in the normally closed (at rest) circuit. Increases in the total circuit resistance, caused by an open mounting switch or a sensor normally closed contact problem or decreases in circuit resistance due to a leakage path, would be detected. Such failures would turn on the warning light.

In order to check the electronic circuit itself, upon power up, the warning light is made to turn on briefly if there are no detected malfunctions. The time interval during which the light is on during power up is called test time, and is about 5 seconds in duration. The truth table for the diagnostic fuction is thus:

	Light On	Light Off
Test Time	OK	Failure
Later	Failure	OK

The list of failures checked and their resulting indications is given in Table VI.

The diagnostic circuit diagram is shown in Figure 4. Twelve functional parts have been blocked off for reference.

Block 1 shows the wiring of an individual sensor. If the sensor is nominal and at rest, the normally closed circuit is cloced, and half the power supply voltage appears at the tap of the voltage divider. A small leakage current flows through the squibs. Should the squibs, the mounting switch, or the normally closed contact open or increase somewhat in resistance, the voltage at the tap of the divider will rise. Should there be leakage to ground or V supply, the voltage at the tap will fall or rise respectively. The diagnostic circuit detects a variation of 20% or more in the nominal voltage at the tap. When the sensing mass moves so as to close the normally open contacts during a crash, the resistors are shorted out and the resistance of the resulting circuit is primarily that of the squibs. At that time the auxiliary power supply capacitor provides the energy to fire the squibs.

Block 2 is simply the power supply for the electronics. Block 3 contains transient suppressors to prevent damage to the low voltage electronic components from short duration voltage spikes coming through the sensor wiring. Transients on the main power supply are adequately filtered by either the storage capacitor or the bypass capacitors C1, C2, and C3.

In normal operation, Block 4 further divides the sensor readiness voltage down to the range suitable for the electronic parts. Block 5 contains the high and low comparators, which monitor this voltage. The high and low comparator outputs are ORed for each sensor for out-of-range indication.

Block 6 is a resistor OR which takes the output from one or more Ored comparators and turns on the transistors in Block 7, thereby lighting the warning lamp.

In normal operation the above mentioned blocks detect

TABLE VI

Major Failures Detected By The Diagnostic Circuit And Their Indications

Condition	Warning Light Test Time	Warning Light Later
NOMINAL	ON	OFF
Squibs open	ON	ON
Mounting switch open	ON	ON
Sensing mass not in "at rest" position	ON	ON
Sensing mass in firing position	OFF	OFF
Leakage inside sensor	ON	ON
Storage capacitor shorted	ON	ON
Power supply below 14 volts	ON	ON
Warning light burned out	OFF	OFF
C4 shorted	ON	ON
C4 open	OFF	OFF
U1 pin 13 always low	ON	ON
U1 pin 13 always high	OFF	OFF
U1 pin 14 always low	OFF	OFF
U1 pin 14 always high	ON	ON
U1 pin 2 always low	OFF	OFF
U1 pin 2 always high	ON	ON
U2 pin 2 always low	OFF	OFF
U1 pin 2 always high	ON	ON
Q1 shorted	ON	ON
Q1 open	OFF	OFF
Q2 shorted	ON	ON
Q3 shorted	ON	ON
U3 pin 10 always low	OFF	OFF
U3 pin 10 always high	ON	ON
U3 pin 4 always low	OFF	OFF
U3 pin 4 always high	ON	ON
U3 pin 11 always low	ON	ON
U4 pin 13 always low	ON	ON
U4 pin 13 always high	OFF	OFF
U4 pin 1 always low	OFF	OFF
U4 pin 1 always high	ON	ON
Q4 open	OFF	OFF
Q4 shorted	ON	ON
Q5 open	OFF	OFF
Q5 shorted	ON	ON

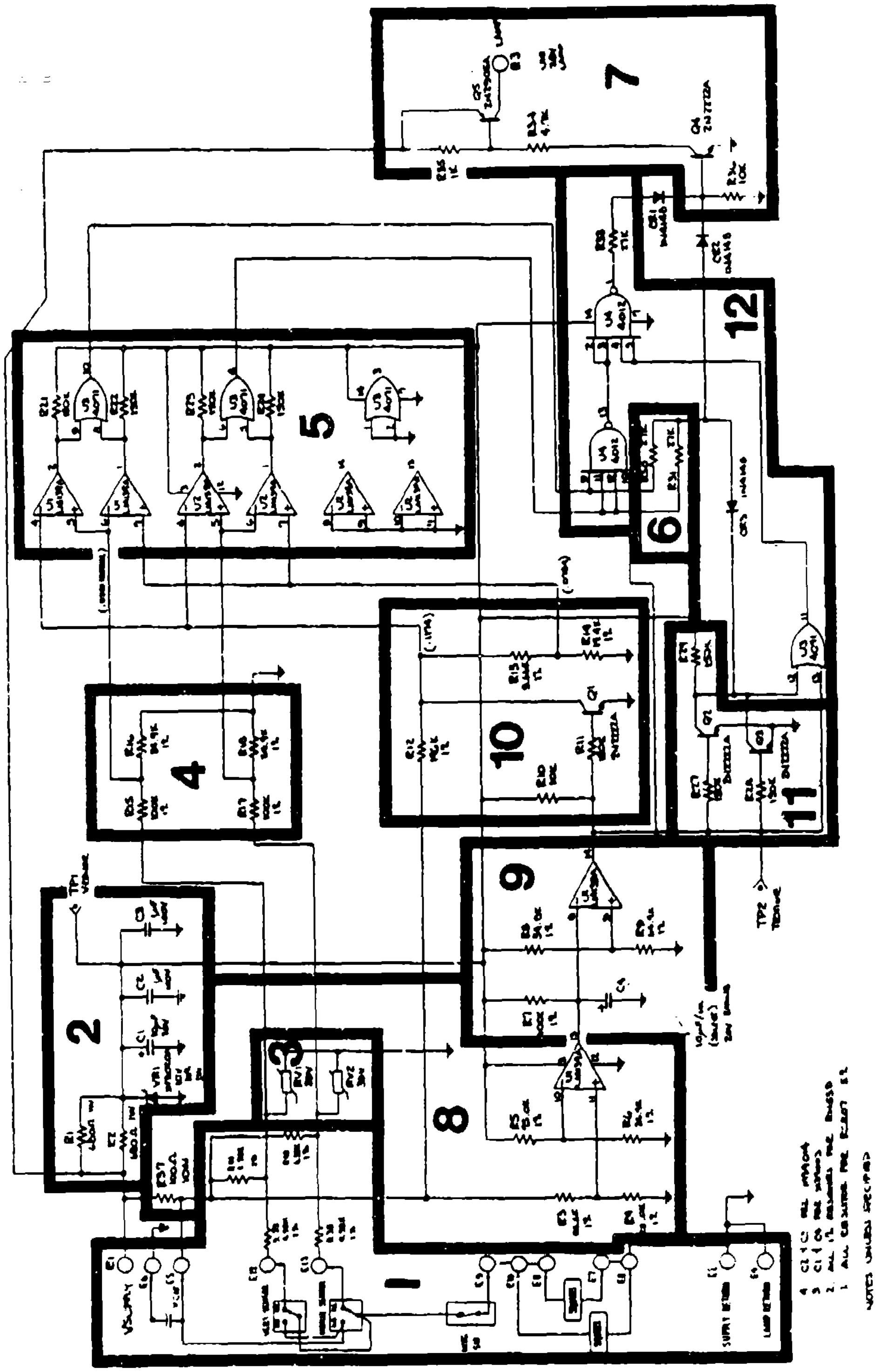


Figure 4 - Diagnostic Circuit Schematic

failures in the system external to the diagnostic circuit. To test the electronic circuit itself, Blocks 8 through 12 are employed to modify the way Blocks 1 through 7 normally work. This process is done in test time, about 5 seconds in duration at power up.

Block 8 monitors power coming up and does not start the test time interval until the voltage on the auxiliary power supply capacitor is at least 14 volts. Also included in Block 8 is the capacitor charging resistor R37 which limits the current so that if a sensor is inadvertently closed at power up, the squibs will not fire. Block 9 is the test time interval timer. Block 10 pulls the high limit reference voltage to ground (below nominal), thus causing all three high comparators (if they are working) to indicate "bad".

The transistors in Block 11 short the output of the resistor OR to ground so that its signal is not available during test time to turn on the light. If all three comparators and their corresponding OR's are working and the circuit is in test time, Block 12 then supplies the current to turn on the transistors in Block 7. The OR gate in Block 12 is employed to detect a shorted transistor in Block 11.

SYSTEM INTEGRATION AND PACKAGING

The elements of the system consist of:

a) vertical sensor
b) horizontal sensor
c) mounting switch
d) diagnostic circuit board
e) storage capacitor
f) warning light
g) input (power) and output (squib) connectors
h) case for the above with mounting provisions

The entire system is contained in a single package whose size is 173 mm x 86.5 mm x 82 mm. The weight is about 1.5 kg. The large size of the package is due primarily to the storage capacitor. Figure 5 is a photograph of the assembled crash sensor system. Figure 6 gives installation data. Figure 7 is a photograph showing the general arrangement of the system components called out in detail in Figure 8.

SENSOR SYSTEM SPECIFICATION

A preliminary specification for the crash sensor system was developed and is presented below. Modifications to the specifications due to the information learned about the AAH have been included. The rationale behind the specification appears in [2]. The AAH background information is presented in the Appendix.

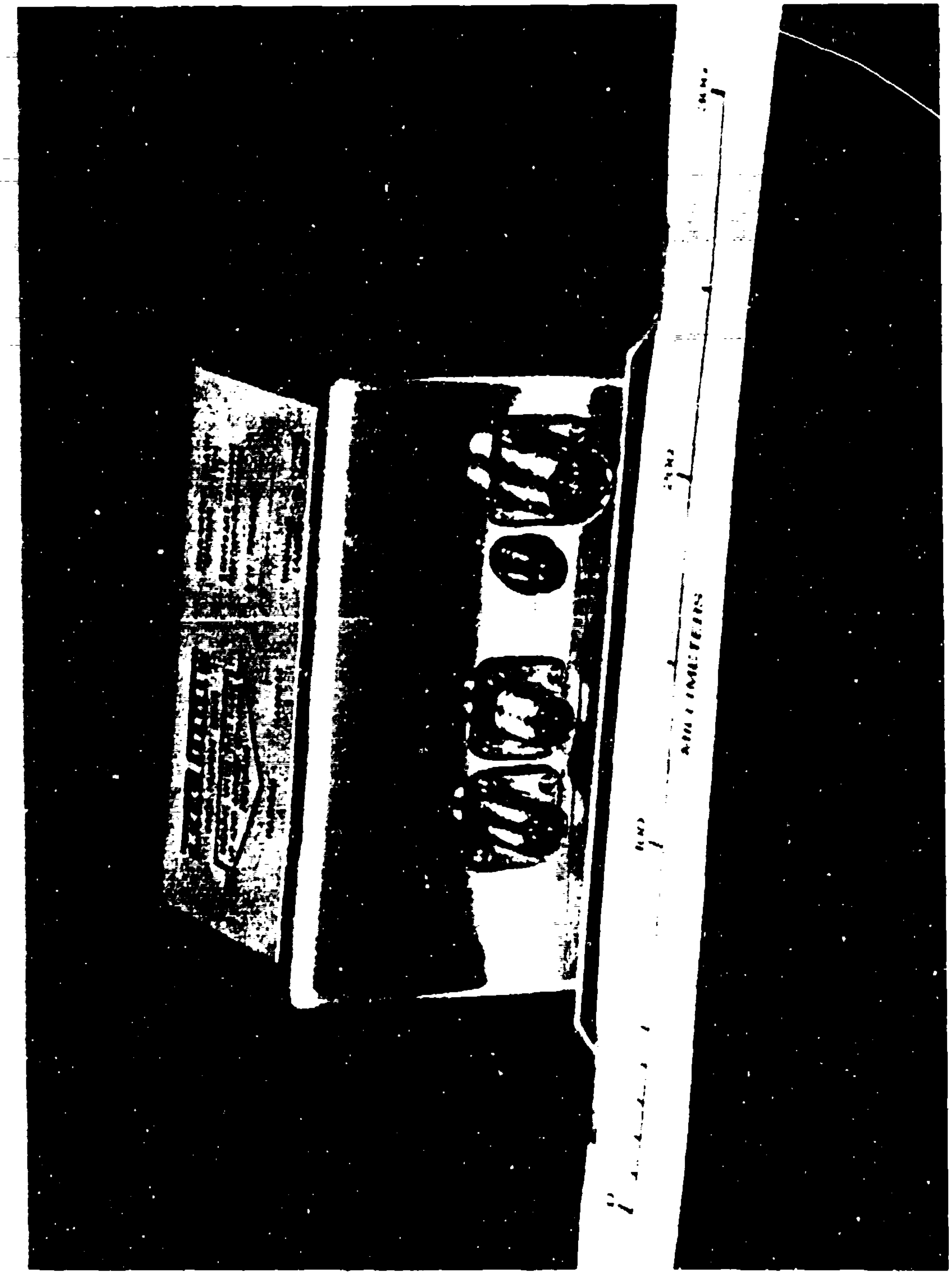
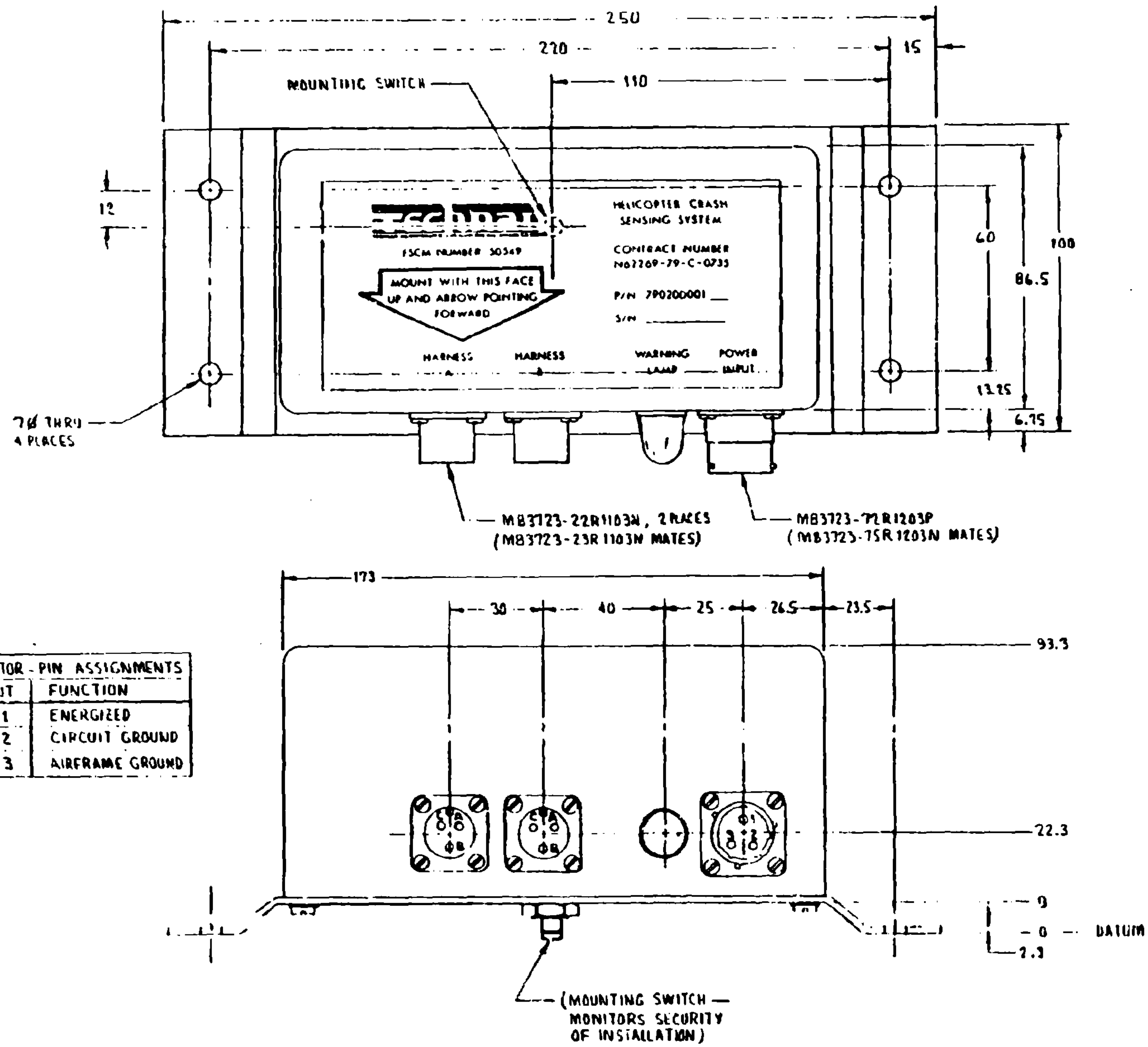


Figure 5 - Assembled Sensor System



CONNECTOR - PIN ASSIGNMENTS	
PIN IDENT	FUNCTION
A OR 1	ENERGIZED
B OR 2	CIRCUIT GROUND
C OR 3	AIRFRAME GROUND

Figure 6 - Crash Sensing System Installation Data

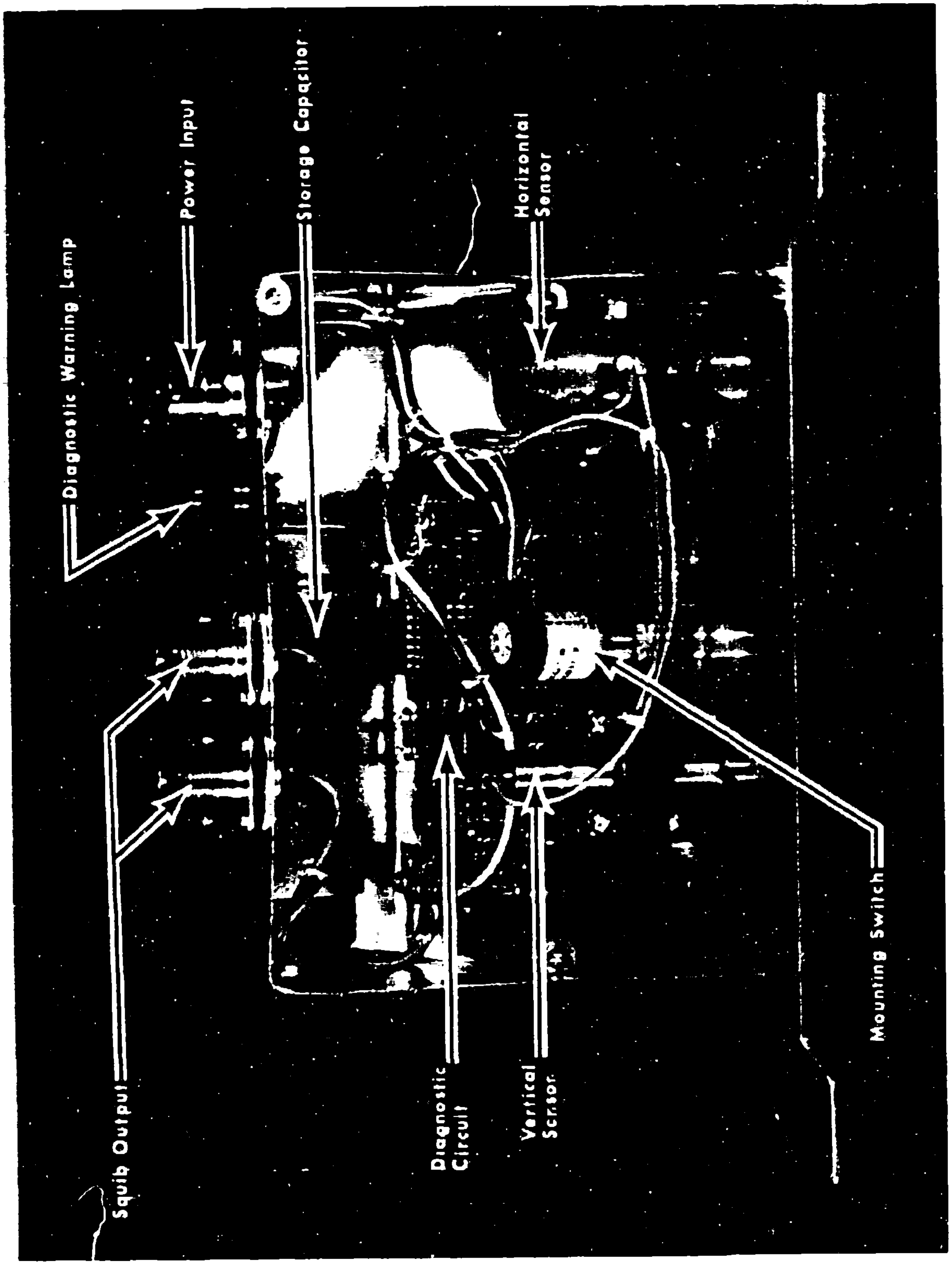


Figure 7 - Internal Arrangement of Sensor System

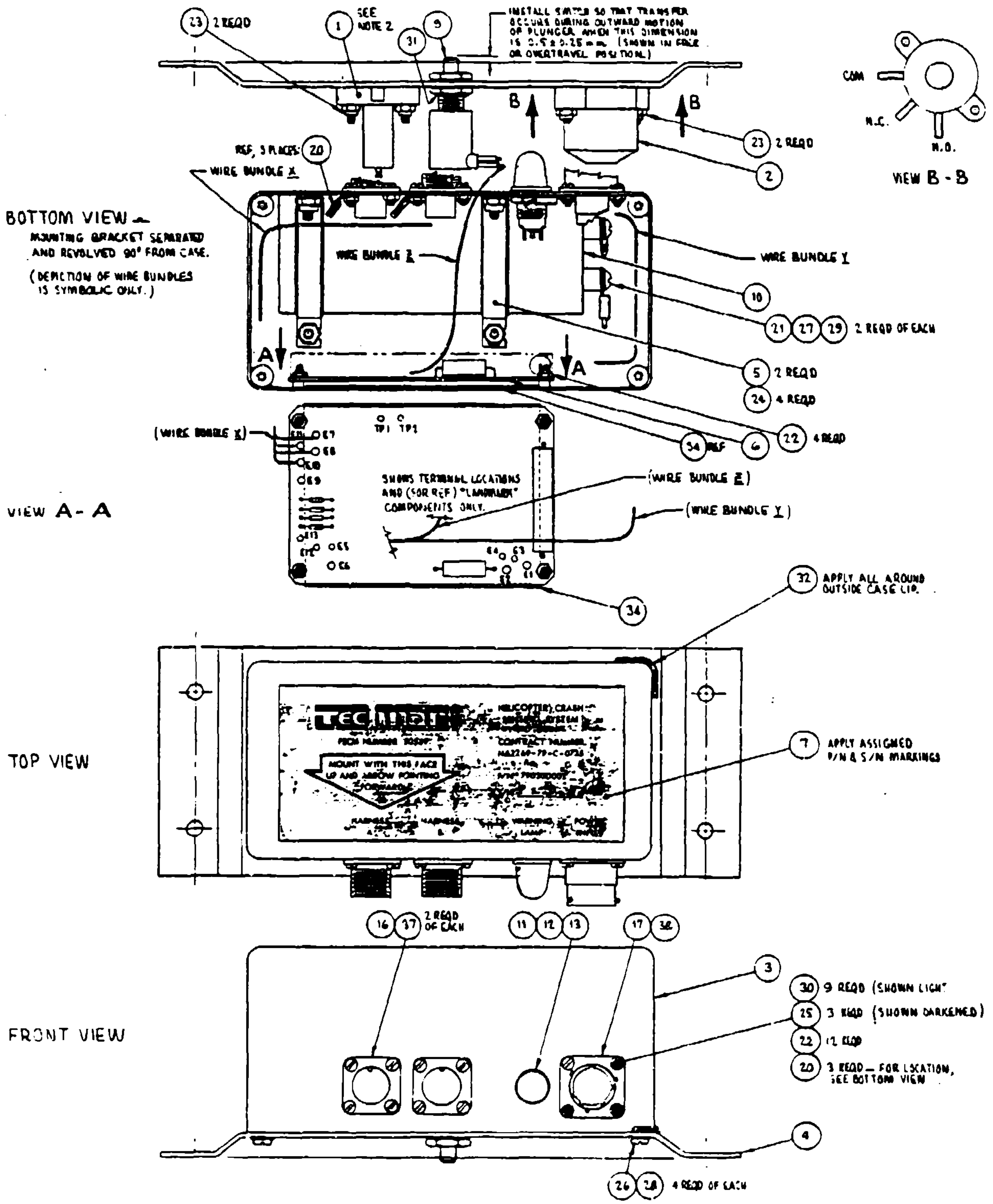


Figure 8 - Sensor System Final Assembly

WIRE LIST						
ITEM	AWG	COLOR	LENGTH	FROM	TO	BUNDLE
W1	16	RED	260	(16)A, P1	(6) E10	X
W2	16	BLK	260	(16)A, P2	(6) E8	X
W3	16	BLK	60	(16)A, P3	⏚	–
W4	16	RED	260	(16)B, P1	(6) E11	X
W5	16	BLK	260	(16)B, P2	(6) E7	X
W6	16	BLK	60	(16)B, P3	⏚	–
W7	20	WHT	265	(12) CTR	(6) E4	Y
W8	20	BLU	265	(12) SHELL	(6) E3	Y
W9	16	RED	270	(17) P1	(6) E1	Y
W10	16	BLK	270	(17) P2	(6) E2	Y
W11	16	BLK	60	(17) P3	⏚	–
W12	16	BLK	300	(10) (–)	(6) E6	Y
W13	20	WHT	300	(10) (+)	(6) E5	Y
W14	16	RED	410	(10) (+)	(2) N.O.	Y&Z
W15	16	RED	125	(2) N.O.	(1) N.O.	Z
W16	16	BLK	115	(1) COM	2 COM	Z
W17	△4	(WHT)	60	(9) LEAD 3	(2) COM	Z
W18	△4	(WHT)	260	(9) LEAD 1	(6) E9	Z
W19	20	GRN	300	(1) NC	(6) E12	Z
W20	20	BLU	300	(2) NC	(6) E13	Z

LACE WIRE BUNDLES USING ITEM 35 AS REQD. GENERAL ROUTING OF WIRE BUNDLES IS SHOWN IN VIEWS.

NOTE:

△1 THESE ITEMS ARE MATING PLUGS AND ACCESSORIES FURNISHED WITH ASSY.

2. IDENTIFICATION OF VERTICAL-SENSOR TERMINALS:
   - COMMON: IN BASE; HAS BARE WIRE LEADING INTO SENSOR.
   - NO: IN BASE.
   - NC: ON OUTER END.

△3 SOLDER ALL ELECTRICAL CONNECTIONS EXCEPT THOSE USING CRIMP OR SCREW TERMINATIONS.

△4 THESE WIRES (NO. 20 AWG, REF) ARE PART OF ITEM 9 SWITCH. CUT OFF UNUSED WIRES (LEADS 2,4,5,6) APPROX 20 mm FROM SWITCH BODY.

5. TIGHTEN ALL ELASTIC STOP NUTS TO 12 INCH-POUNDS (1.35 NEWTON-METRES) TORQUE.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ITEM
1		10-36675-12	GASKET	BENDIX CORP ELECTRICAL COMPONENTS DIV SIDNEY, NY 13838	38
2		10-36675-10	GASKET		37
SEE WIRE LIST TABULATION			WIRE, ELECTRICAL (19-STRAND)	MIL-W-16878 TYPE B, 600V	36
AR			TAPE, LACING	MIL-T-43435 TYPE I, SIZE 3	35
AR		P-221	TAPE, KAPTON	PERMACEL NEW BRUNSWICK, NJ	34
AR △3			SOLDER	MIL-STD-454 REQMT 5	33
AR		RTV162	SEALANT	GEN'L ELECTRIC WATERFORD, NY	32
AR		EA-956	ADHESIVE, EPOXY	HYSOL (DIV DEXTER) PITTSBURG, CA	31
9		NO. 4-40 UNC × 9.5 mm (.38 IN) LG	SCREW, MACHINE, PAN-HEAD, SLOTTED	CRES	30
2		NO. 10	WASHER, INTERNAL-TOOTH	CRES	29
4		NO. 8	WASHER, INTERNAL-TOOTH		28
2		NO. 10-32 UNF × 8 mm (.31 IN) LG	SCREW, MACHINE, PAN-HEAD, SLOTTED		27
4		NO. 8-32 UNC × 12.7 mm (.5 IN) LG	SCREW, MACHINE, PAN-HEAD, SLOTTED		26
3		NO. 4-40 UNC × 8 mm (.31 IN) LG	SCREW, MACHINE, PAN-HEAD, SLOTTED	CRES	25
4		F22NM-82	NUT, ELASTIC STOP (NO. 8-32 UNC)	ESNA DIV AMERACE CORP UNION, NJ 07083	24
4		F22NM-62	NUT, ELASTIC STOP (NO. 6-32 UNC)		23
16		F22NM-40	NUT, ELASTIC STOP (NO. 4-40 UNC)		22
2		41107	TERMINAL, RING-TONGUE, CRIMP (NO. 10 STUD)	AMP INC (OR EQ) HARRISBURG PA 17105 (MS-25036)	21
3		31878	TERMINAL, RING-TONGUE, CRIMP (NO. 4 STUD)		20
1 △1		M83723-15S-12R	CABLE CLAMP	MIL-C-83723	19
2 △1		M83723-35S-11R	BACKSHELL		18
1		M83723-72R1203P	RECEPTACLE		17
2		M83723-72R1103N	RECEPTACLE		16
1 △1		M83723-75R1203N	PLUG		15
2 △1		M83723-73R1103N	PLUG	MIL-C-83723	14
1		LC35RT2	LENS (SPECIFY COLOR: RED)	MIL-L-3661	13
1		LH89/1	LAMPHOLDER	MIL-L-3661	12
1		387	LAMP	DIALCO, OR EQ	11
1		M39018/4-2134M	CAPACITOR (18000 μF, 40 V DC)	MIL-C-39018	10
1		MS27240-1	SWITCH		9
					8
1		79020B026	NAMEPLATE		7
1		79020D012	PRINTED WIRING ASSY		6
2		79020B007	BRACKET, CAPACITOR		5
1		79020C006	MOUNTING BRACKET ASSY		4
1		79020D005	CASE ASSY		3
1		79020C004	HORIZONTAL SENSOR ASSY		2
1		79020C003	VERTICAL SENSOR ASSY		1

PARTS LIST

Figure 8 - Sensor System Final Assembly (cont.)

Acceleration Threshold:

The system shall not fire when subjected to an acceleration pulse anywhere in the "NO FIRE" region of Figure 9 (Vertical Axis) or Figure 10 (Horizontal Plane).

The system shall fire when subjected to an acceleration pulse anywhere in the "MUST FIRE" region of Figure 9 (Vertical Axis) or Figure 10 (Horizontal Plane).

Response Time and Closure Duration:

The maximum time to fire (TTF) and minimum contact closure duration (DUR) are given below.

Vertical Sensor:	Half sine pulse G =10	t=15 msec
	TTF = 16 msec	DUR = 5 msec
Horizontal Sensor:	Rectangular pulse G =6	t=12 msec
	TTF = 15 msec	DUR = 5 msec

Vibration Operating:

The diagnostic warning lamp shall not light (indicating a sensor not maintaining closure of the normally closed circuit) when subjected to the vibration curve in Figure 11.

Contact Resistance:

The resistance of the normally closed contact of the sensor shall not exceed 500 milliohms. The resistance of the normally open contacts of the sensors, when closed by the application of 10 g's shall not exceed 100 milliohms.

Current Carrying Capacity:

The normally open contacts of each sensor shall be capable of carrying 85 amperes for 250 μsec.

Electrical Energy Storage:

The system shall be capable of supplying 17.8 amperes for at least 3 milliseconds to a load of .23 ohms after having been disconnected from the aircraft power supply for up to 5 seconds.

Mounting Force:

The mounting switch shall require at least 25N to actuate.

Fault Indication:

The system shall be capable of detecting the following system failures and of providing an indication of failure via the diagnostic warning lamp.

a) Squibs open
b) Mounting switch open
c) Sensing mass not in "at rest" position
d) Sensing mass in firing position
e) Electrical leakage inside sensor
f) Storage capacitor shorted

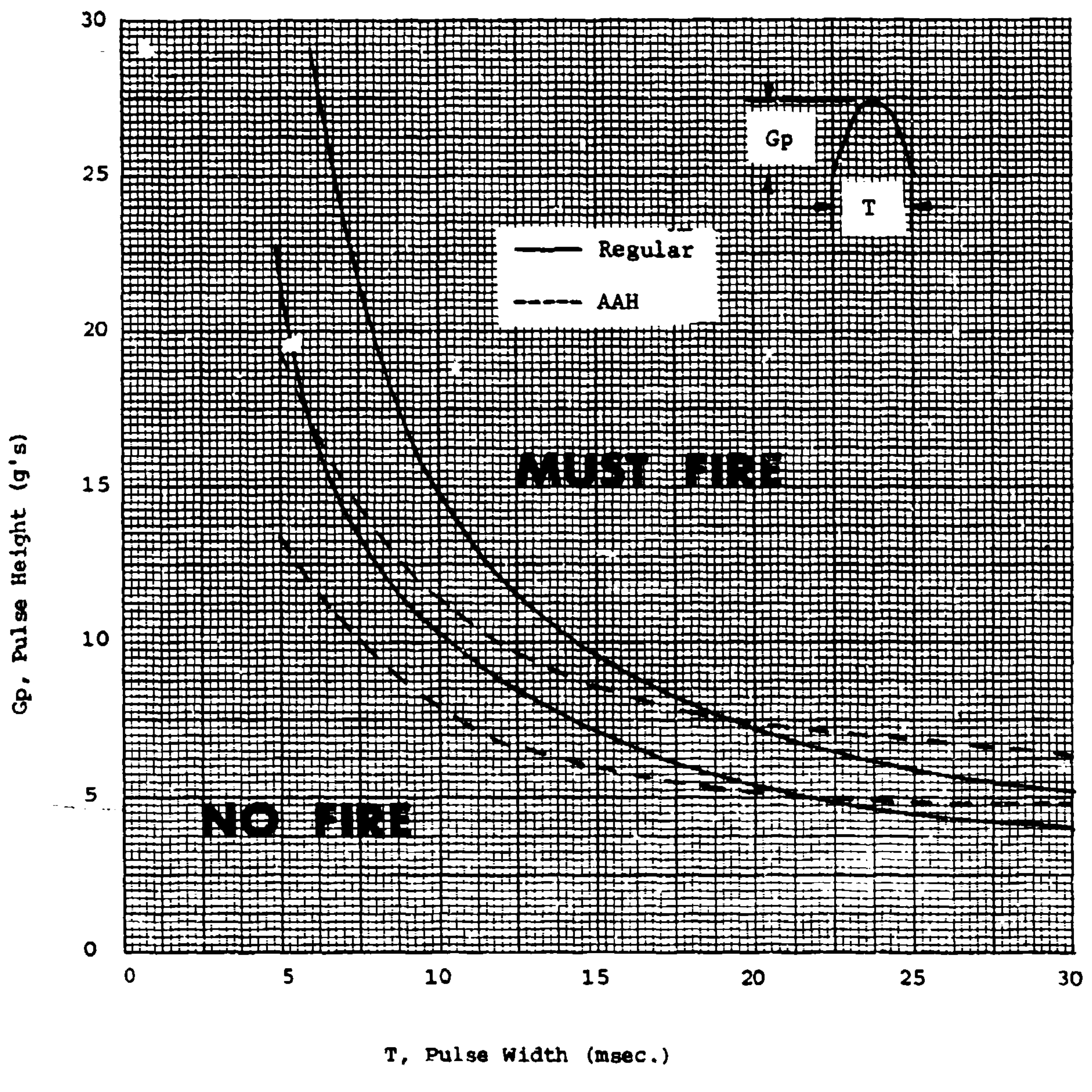


Figure 9 - Vertical Sensor Threshold Requirements

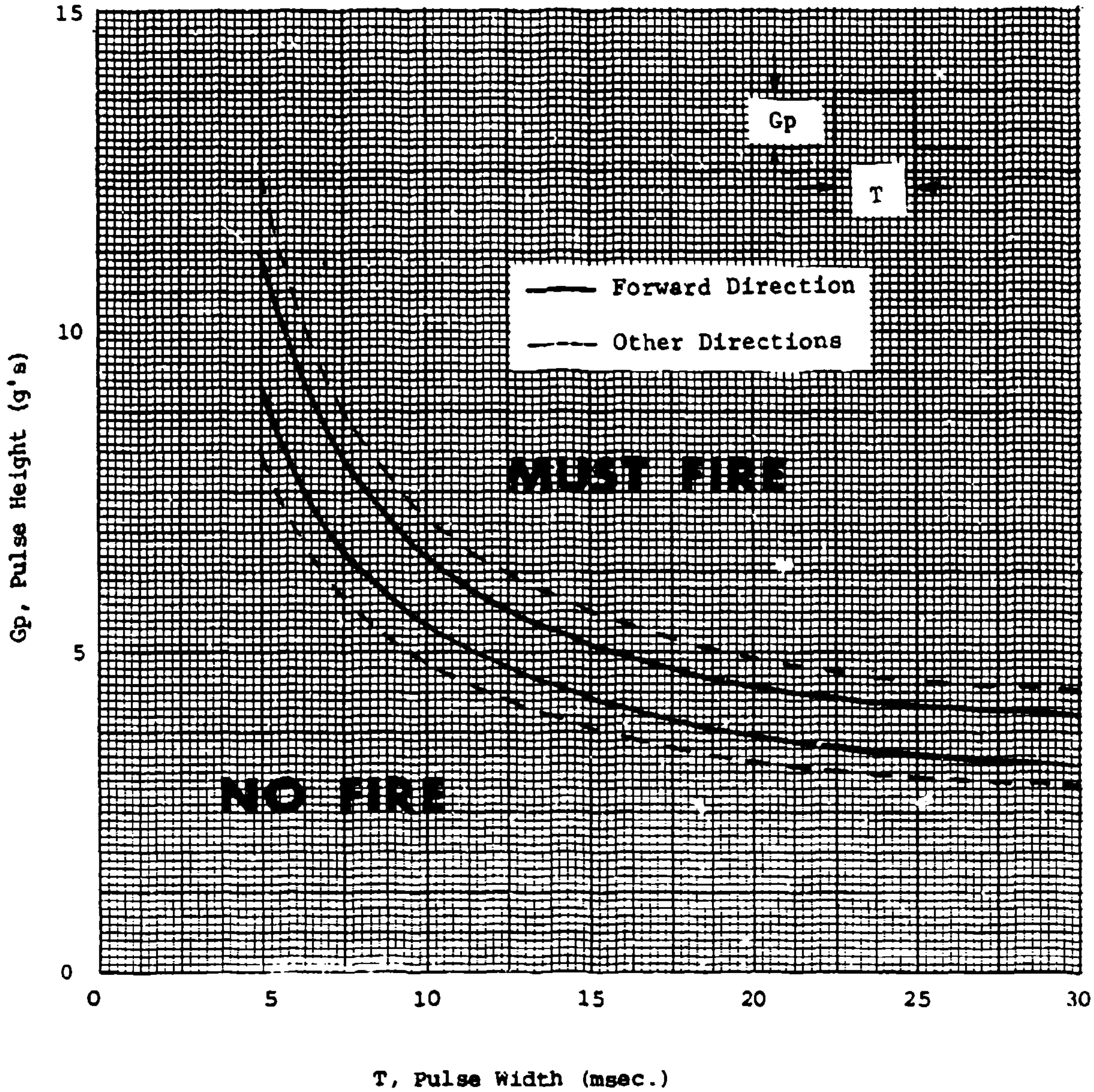


Figure 10 - Horizontal Sensor Threshold Requirements

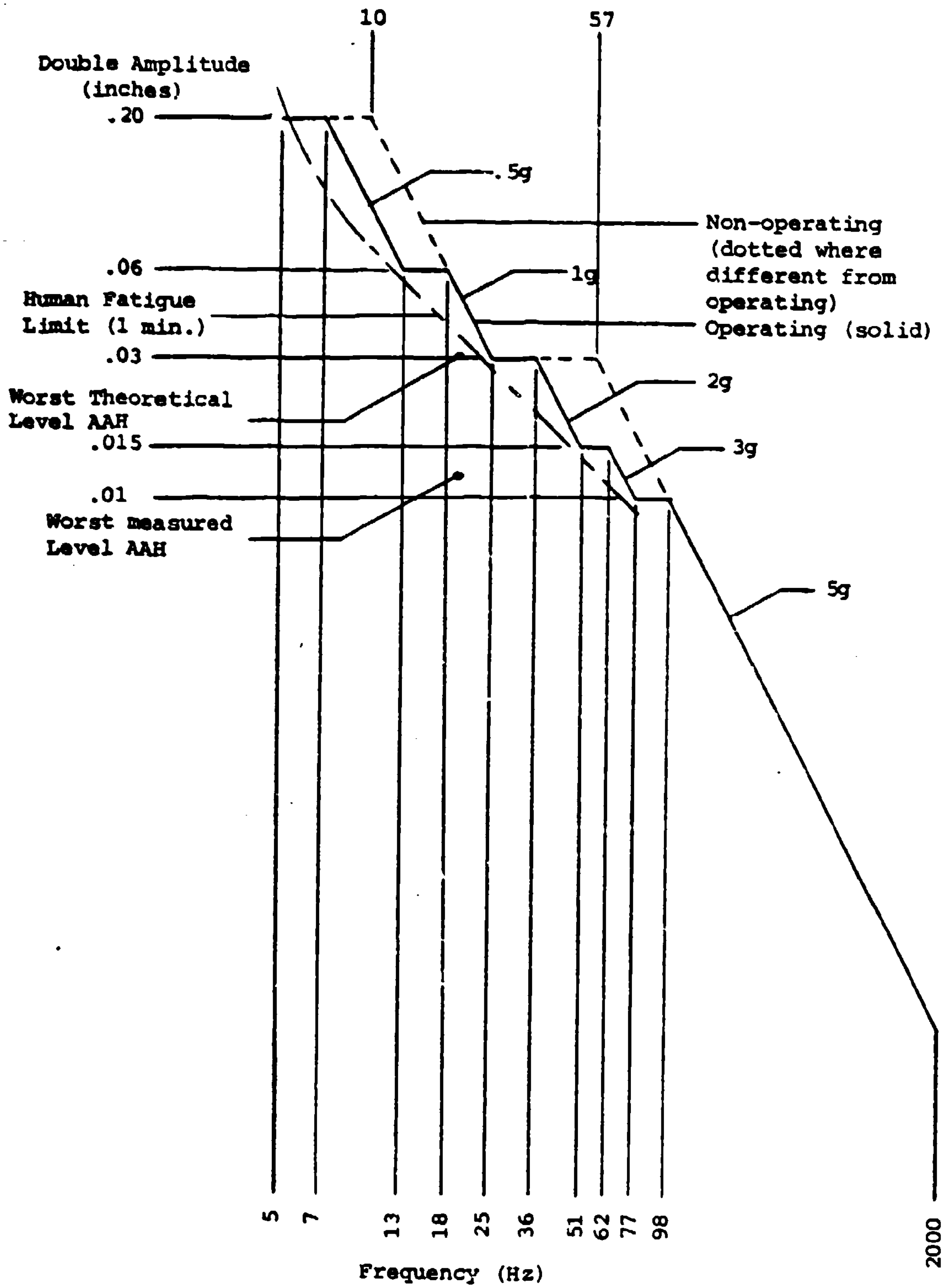


Figure 11 - Operating Vibration Requirements

g) Power supply below 12.5 volts
h) Warning light burned out
i) Failures of semiconductors in the diagnostic circuit

Detection and indication via the warning lamp of any single failure is required. Detection and indication of multiple failures is not required.

Weight, Size:
The mass of the system shall not exceed 2.4 Kg. The size of the system shall not exceed 1250 cm^3.

Electrical Interface Requirements:
The electrical schematic for the system shall be as in Figure 12.

Life:
The storage life of the system shall be at least 5 years. The operating life shall be a minimum of 5000 hours or 10 squib firings.

Erratic Performance:
At any time during its operation the system shall not exhibit abnormal behavior or erratic performance even though such behavior is within the limits of performance specified herein.

Insulation Resistance:
The resistance from case to any other input or output pin shall be at least 10 megohms at 250 VDC.

Strength of Enclosure:
The system shall be contained in a single, rugged metal can capable of protecting the system from damage during a 95th percentile potentially survivable crash.

Altitude:
The system shall operate within limits when tested according to MIL-STD-810C, Method 500.1, Procedure I.

High Temperature - Operating and Storage:
The system shall operate within limits during and following testing according to MIL-STD-810C, Method 501.1, Procedure I, except that the temperatures in steps 2 and 4 shall be 85°C.

Low Temperature - Operating and Storage:
The system shall operate normally at -55°C following storage at -65°C in accordance with MIL-STD-810C, Method 502.1, Procedure I.

Humidity:
The system shall operate normally when tested in accordance with MIL-STD-810C, Method 507.1, Procedure I.

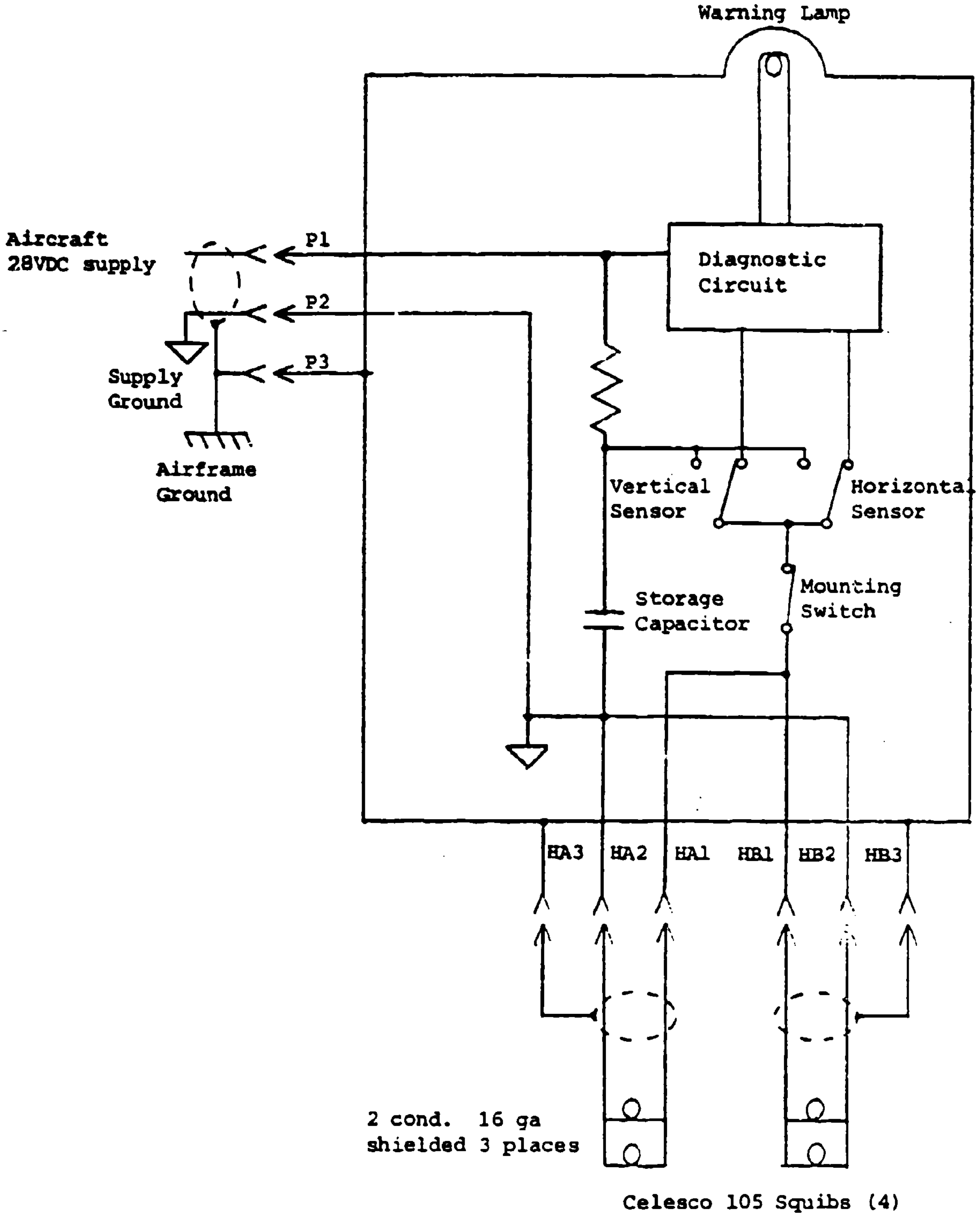


Figure 12 - Sensor System Electrical Schematic

Sand and Dust:
The system shall operate normally following exposure to dust per MIL-STD-810C, Method 510.1, Procedure I.

Vibration, Non-Operating:
The system shall operate normally following exposure to sinusoidal vibration in accordance with MIL-STD-810C, Method 514.2, part 1, curve M.

Shock:
The system shall operate normally after testing in accordance with MIL-STD-810C, Method 516.2, Procedures II (transit drop) and III (crash safety).

Voltage Range:
The system shall operate normally over a steady state voltage range of 22 to 29 VDC (Ref. MIL-STD-704C, Table II).

Voltage Transients:
The system shall operate normally when subjected to the transient voltage conditions given by Figure 10 of MIL-STD-704C (reproduced herein as Figure 13).

Overvoltage and Undervoltage:
The system shall operate normally when subjected to the overvoltage and undervoltage conditions given by Figure 12 of MIL-STD-704C (reproduced herein as Figure 14).

Weapons System Firing:
The system shall not fire when subjected to the simulated gunfire vibration tests of MIL-STD-810C, Method 519.2. Note that the parameters needed to describe such a test are dependent on the geometry of the aircraft and the weapon location, number, and type. Analysis of a specific installation is likely to show that because of the centralized location (between pilot and co-pilot seats on the floor) the system will be sufficiently far removed from the weapons so as to make this testing unnecessary.

Electromagnetic and Electrostatic Interference:
It is unnecessary to specify or test for these environments due to the metal can protecting the system which acts as a shield.

Hazards of Electromagnetic Radiation to Ordnance (HERO):
The electronic activity of the system is essentially DC; thus no EMR will be produced. No testing is necessary.

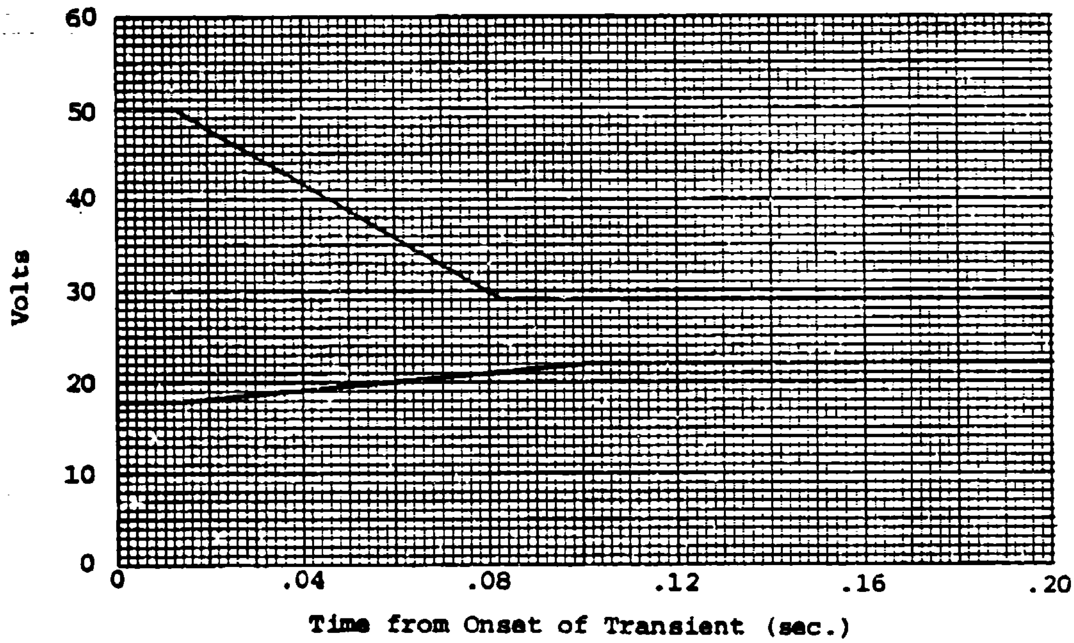


Figure 13 - MIL-STD-704C Voltage Transients

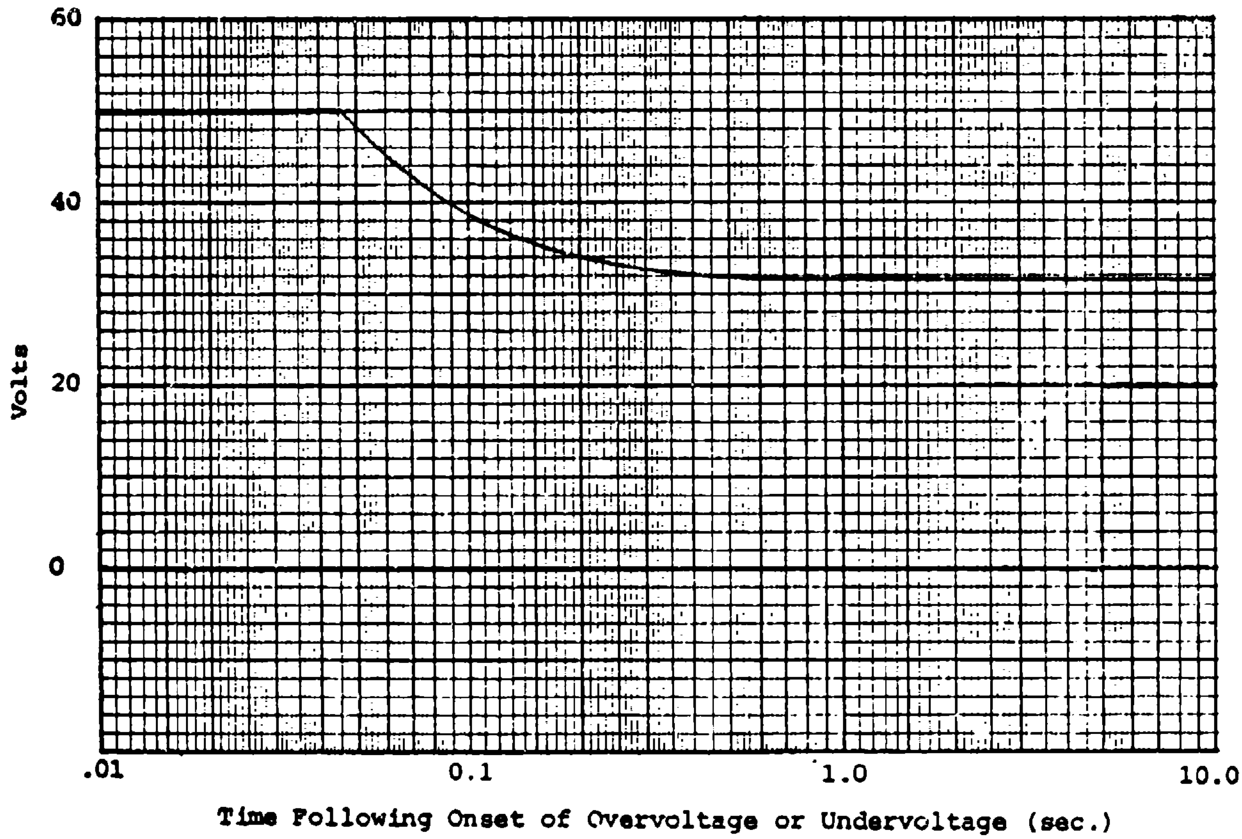


Figure 14 - MIL-STD-704C Under and Over Voltage

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APPENDIX

BACKGROUND FOR DESIGN AND SPECIFICATION MODIFICATIONS FROM AAH DATA

Late in Phase II it was learned that the Advanced Attack Helicopter (AAH) can perform a 3.5 g climb maneuver of sufficient duration that a vertical sensor calibrated to the original threshold curve would fire. The asymptote of the original curve was 2.5 g's. A new threshold curve was generated whose asymptote is 3.7 g's (above the 3.5 g's of the maneuver). This is accomplished by increasing the bias g-level due to the bias spring. Its free length was increased. To compensate for this reduced sensitivity the amount of gas damping was reduced by enlarging the orifice slightly. The result is a threshold curve somewhat flatter than the original (see Figure 9). Computer simulations were performed to verify satisfactory performance on all acceleration histories.

At the same time the 3.5 g maneuver was investigated, measured vibration data was also available. All helicopters with which Hughes Helicopter engineering personnel have had experience have much lower vibration levels than those set forth in MIL-STD-810. Referring to Figure 11, note the two vibration levels appropriate to the AAH. The worst measured level at .22 g's and 19.3 Hz is insignificant. The worst theoretical level at .6 g's and 19.3 Hz is the limit of the AAH structure. Hughes also supplied Technar with a copy of International Standard 2631, Guide for the Evaluation of Human Exposure to Whole-Body Vibration, in which human fatigue limits are presented. The highest vibration levels can be tolerated only for short times. The 1 minute human fatigue limit is plotted as the curved line in Figure 11.

If the operating vibration specification is more severe than both the human fatigue limit (at which the pilot can no longer control the aircraft) and the worst theoretical vibration level (at which the aircraft structure fails) the crash sensing system will perform satisfactorily. Thus, the revised operating vibration level is shown as a solid curve skirting the human fatigue limit curve on the high side. Non-operating vibration levels can remain the same in accordance with MIL-STD-810.

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