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LEVEL II

Final Report

CRASH SURVIVABLE FLIGHT DATA RECORDING SYSTEM STUDY

81-17693

June 30, 1981

Prepared for

Air Force Systems Command
Aeronautical Systems Division, PMR SB
Wright-Patterson AFB, Ohio 45433

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Study reviews the requirements and available technology for crash survivable flight data recording systems. Primary efforts relate to fighter/attack aircraft, with the A-10, F-15 and F-16 used as specific examples. Results include design and performance characteristics of recommended systems and an analysis showing a high cost-effectiveness for implementation of CSFDRS.

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SECTION 1

INTRODUCTION AND SUMMARY

PROGRAM OBJECTIVE

The U.S. Air Force currently loses about 75 fighter, trainer, and attack aircraft each year in major accidents. Each aircraft crash is investigated to determine the cause. The provision of a crash survivable flight data recorder (CSFDR) system that provides data for that investigation would improve the investigation effectiveness such that actions could be taken resulting from the findings to prevent reoccurrence. If this should reduce the number of future accidents even by a few percent, the consequent cost savings would be substantial. There has been therefore a requirement for the investigation of the installation of a CSFDR system into those aircraft types.

Current CSFDR systems were designed for the commercial aircraft field and are too bulky and heavy to be considered for these high-density aircraft. With recent improvements in technology, particularly crash protection techniques, data storage, and data processing and compression, it is possible to build systems that are considerably lighter and smaller than previously designed.

Accordingly, this program has been undertaken to attempt to provide the U.S. Air Force with information adequate to determine whether a CSFDR development program should be begun. Specific questions to be answered include:

- Performance requirements for a CSFDR
- Technology advances appropriate to a modern CSFDR design
- Size, weight, and life-cycle cost penalties of a CSFDR
- Expected system benefits and benefit/cost ratio
- Required detailed technological developments that could be undertaken to improve the benefit/penalty performance

Although the program undertaken by AiResearch, together with Normalair-Garrett Limited (NGL) as coinvestigator, has been modest in funded scope of effort, the essential program objectives have been met. The provision of CSFDR systems for these aircraft would be highly cost effective, and development can and should begin now in order to minimize losses of aircraft and lives.

PROGRAM METHODS OVERVIEW

The organization of the study has proceeded essentially as outlined in the AiResearch-NGL proposal and is shown in Figure 1-1. The sequence has been as follows:

- Obtain data to define system requirements
- Evolve consensus requirement set

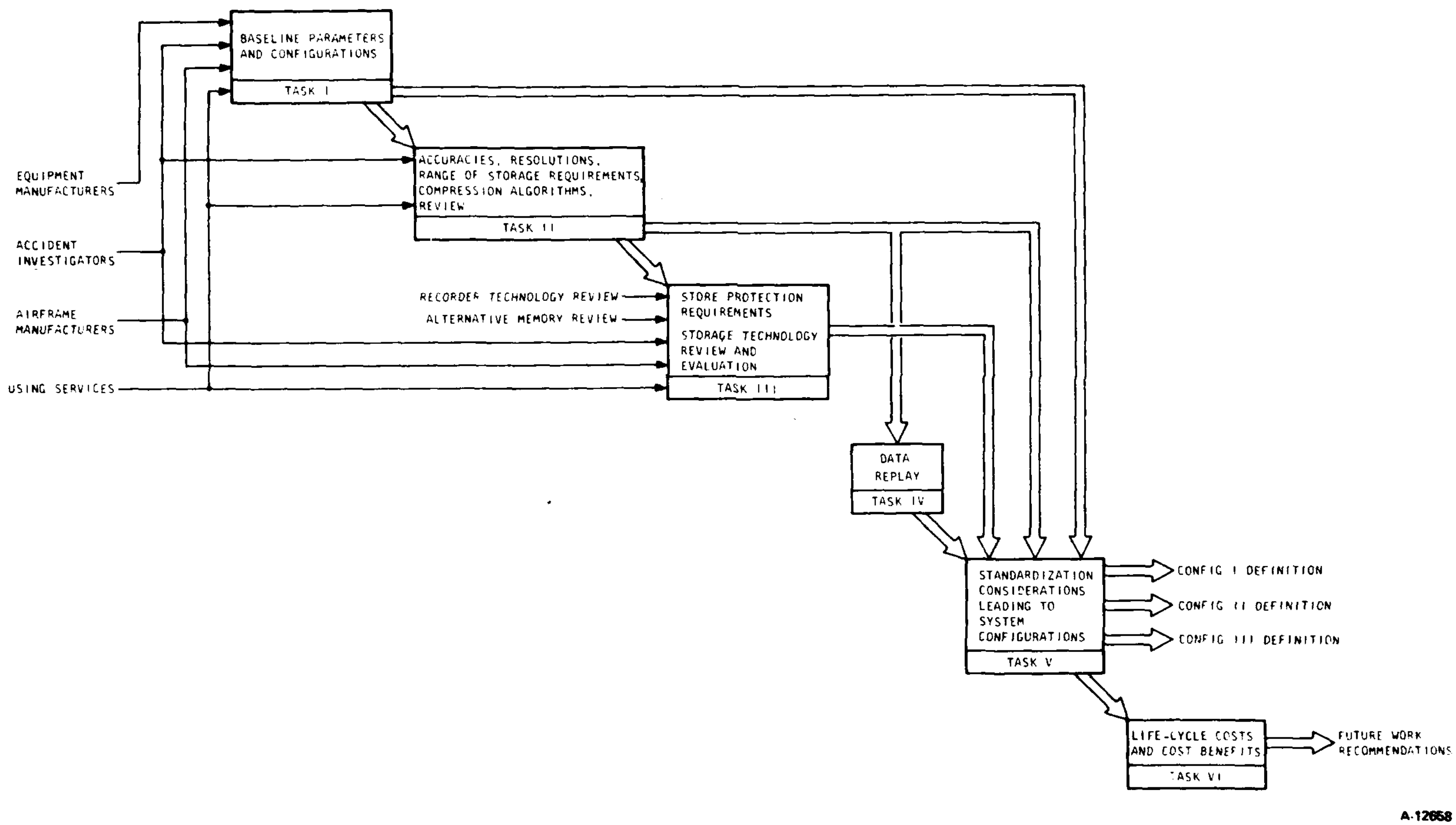

Figure 1-1. Overview of CSFDR Study Program Methods and Procedures

- Review available technology
- Develop configurations to apply this technology to the requirements
- Develop potential benefits and costs

The initial task obtained a substantial data base from which to develop system requirements. Accident investigation authorities were interviewed, including military program and safety offices, civilian aviation safety authorities, and aircraft manufacturers, both in the U.S. and in Europe. Reports on these interviews are included in Appendix G.

The data base was next resolved into actual system capability requirements. An analytic procedure was developed, which resulted in a well-substantiated list of priorities for those parameters that should be stored. Less unanimity was evident in the matter of data sampling rates, and a major program effort was expended to compare data compression algorithms and to evolve a technique that would minimize the data storage size requirement without sacrificing the ability to follow aircraft and system dynamics. The requirements for survivability were also reviewed in an attempt to determine the relevance of transport aircraft digital flight data recorder (DFDR) system survivability specifications to the CSFDR problem for fighter aircraft.

The technology review was relatively conventional in all but two aspects--survivability and data storage. Testing was accomplished for certain data store protection techniques. Data storage technology was evaluated, with emphasis on high-density magnetic tape and the emerging electrically-alterable solid-state devices.

System configurations were developed to satisfy the range of CSFDR system requirements. These included the three alternative configurations specified in the program statement of work, as well as some further alternatives that could not be definitively resolved by the contractor. No effort was made to design exotic device or packaging technology into the data acquisition and processing segment of the system; costs, including maintainabilty costs, were the controlling factor in this segment. However, in the data storage element, some technology push is assumed in order to minimize size and weight of the protection subsystem and the weight and balance impact of the data storage module.

Estimates were made of system acquisition and other cost elements relevant to the life-cycle cost. An estimate was also made of the potential and predicted savings, based on recent accident history and probable improvements in resolution of accident causes.

SUMMARY OF CONCLUSIONS

Parameter Selection and Sampling Rates

The table of selected parameters and sampling rates from Section 3 is shown here as Table 1-1. The sampling rates are designed to keep successive samples within the accuracy band for most aircraft operations, with some

TABLE 1-1

PARAMETER PRIORITIES ACCURACY AND SAMPLING RATE REQUIREMENTS

	Max. Rate of Change, percent per sec	Required Accuracy, percent	Sampling Rate, per sec	Word Length, bit
Airspeed	4	1	2	11
Altitude	1.6	0.125	8	12
Normal Load Factor	100	0.6	16	9
Engine rpm N_2	20	2	1	8
Elevator Position	100	4	8	7
Aileron Position	100	4	8	7
Rudder Position	200	4	8	7
Flap Position		6	1	6
Engine Fuel Flow	20	2	1	8
Heading	17	0.5	8	10
Pitch Attitude	17	0.5	8	10
Bank Angle	100	0.5	16	10
Engine EGT	50	2	2	8
Engine rpm N_1	20	2	1	8
Hydraulic Pressure		10	1	6
Generator		10	1	6
Angle of Attack	100	1	16	9
Master Caution*	Discretes	--	1	2 x 16
Yaw Rate	17	2	4	8
Pitch Trim	20	5	1	7
Lateral Acceleration		2	8	8
Power Lever Angle	100	2	1	8
Inverter		10	1	6
Fuel Quantity	0.1	5	1 per 30 sec	7
Radar Altitude	25	0.1	16	11
Leading Edge Flaps	100	5	1	7
Pitch Rate	100	2	8	8
Roll Rate	400	2	16	8
Longitudinal Acceleration		2	8	8
Engine Oil Pressure		10	1	6
Stick Position	100	4	8	7
Cabin Pressure		10	1	6
Outside Air Temperature		1	1	8
Rudder Pedal Position	200	4	8	7
Sink Rate	50	2	8	8

NOTE: Master caution words to include auto pilot, speed brake, and all cautionary discretes.

granularity allowed in signal resolution of maximum rates. In accordance with the primary concerns of most investigative personnel, the parameter selection proved to contain data that primarily defines: (1) the trajectory of the aircraft, (2) the orientation and motion of the aircraft, (3) the response of the aircraft and engines to primary control inputs, and (4) some system characteristics.

The input sampling data rate to the processing unit is approximately 1800 bit/sec for configuration I and 900 bit/sec for configuration II.

Data Compression Algorithm and Storage Capacity

Data compression was a major task in the program. The desire to conceive a system that would be compatible with a solid-state data store of practical size requires the use of data compression to minimize storage requirements. For example, the configuration I data rate of 1800 bit/sec would result in approximately 3-Mbit storage requirement for a half-hour of uncompressed data.

The presently preferred algorithm is a comparatively simple form of delta coding. Sample tests indicate a range of 4 to 10 in available compression ratio from this algorithm, depending upon aircraft dynamics. It is noteworthy that this algorithm is fully reversible; i.e., the complete set of input data can be recovered from the stored information.

Addition of audio data, even for only 10 min of the flight, adds substantially to the storage requirements. For the minimum bit rate expected to reproduce reasonable quality voice and cockpit sounds, an added 3 Mbit is required.

If a maintenance capability is added to the optimum configuration this adds to the storage requirement a further memory between 1 Mbit and 20 Mbit, dependent on the flight duration, degree of onboard processing, and form of maintenance recording undertaken. These results are summarized in Table 1-2.

Standardization

The study confirmed the existence of sufficient commonality between the three primary aircraft, the A-10, F-15, and F-16, to enable the development of a system that would be common to all three. In some cases, there would be a few unused inputs. Also, there would be some software modules not identical between the three aircraft, with programming pins to tell the system which of the included programs to run.

The situation is more complex if tri-service standardization is required. In particular, if the U.S. Air Force does not require audio data and the U.S. Navy does, then the storage modules may not be common, and an added circuit module would be required in the U.S. Navy data processing unit.

Storage Technology

The basic conclusions of the storage media investigation are that magnetic tape and E^2PROM semiconductor devices are the valid contenders, with a decision

TABLE 1-2

CSFDR STORAGE CAPACITY REQUIREMENTS

System	Capacity Requirement
Configuration II, parametric data only	160 Kbit
Configuration I, parametric data only	500 Kbit
Configuration I, data and audio (10 min)	3 Mbit
Configuration I, data and audio (15 min)	4 Mbit
Maintenance storage low requirement	2 Mbit*
Maintenance storage medium	6 Mbit*
Maintenance storage high	16 Mbit*

*Each of these in addition to the selected crash data.

between the two based on memory size and required operational dates. In particular, the ability to build a semiconductor memory at an acceptable cost that will survive the crash environment with acceptable data integrity has yet to be demonstrated. This situation is summarized in Table 1-3 for a range of decision dates for the range of capacities given above in Table 1-2.

TABLE 1-3

STORAGE TECHNOLOGY SELECTION POSSIBILITIES

Storage Capacity Required	March 1981	Nov 1981	Aug 1983
160 Kbit	Tape	Solid-state or tape	Solid-state or tape
500 Kbit	Tape	Solid-state or tape	Solid-state or tape
3 Mbit	Tape	Tape	Solid-state or tape
6 Mbit	Tape	Tape	Solid-state or tape
16 Mbit	Tape	Tape	Tape

RECOMMENDED FOLLOW-ON TASKS

As a result of the study and consideration of the requirements for follow-on work, the following is a recommendation for specific areas of work that should be carried out prior to award of the full-scale development contract.

- Evaluate the technology risk involved in utilizing solid-state memory by using development hardware to assess the performance in the required operational and crash environments and their effects on the data integrity.

- Investigate in more depth the degree of information to be obtained for accident investigation from audio recording including the use of free-area microphones.

- Further evaluate compression techniques using real aircraft data to determine the practical degree of compression, the applicability of entropy encoding, and methods using the interrelationship of parameters.

- Evaluate in detail the requirements for tri-service standardization, and define the impact upon system requirements.

At this time, it is recommended that any full-scale development program should develop a storage module interface that would enable utilizing either a tape recorder or a solid-state solution; this recommendation is due to the undemonstrated capability, cost, and availability of nonvolatile solid-state memories. This recommendation could change as a result of the evaluations recommended above.

TASK FLOW DIAGRAMS REFERENCING

The proposal for this CSFDR study contained flow charts for the tasks to be performed. These flow charts are re-presented in this section showing the results of the study and reference to the report section that details the work carried out (see Figures 1-2 through 1-7).

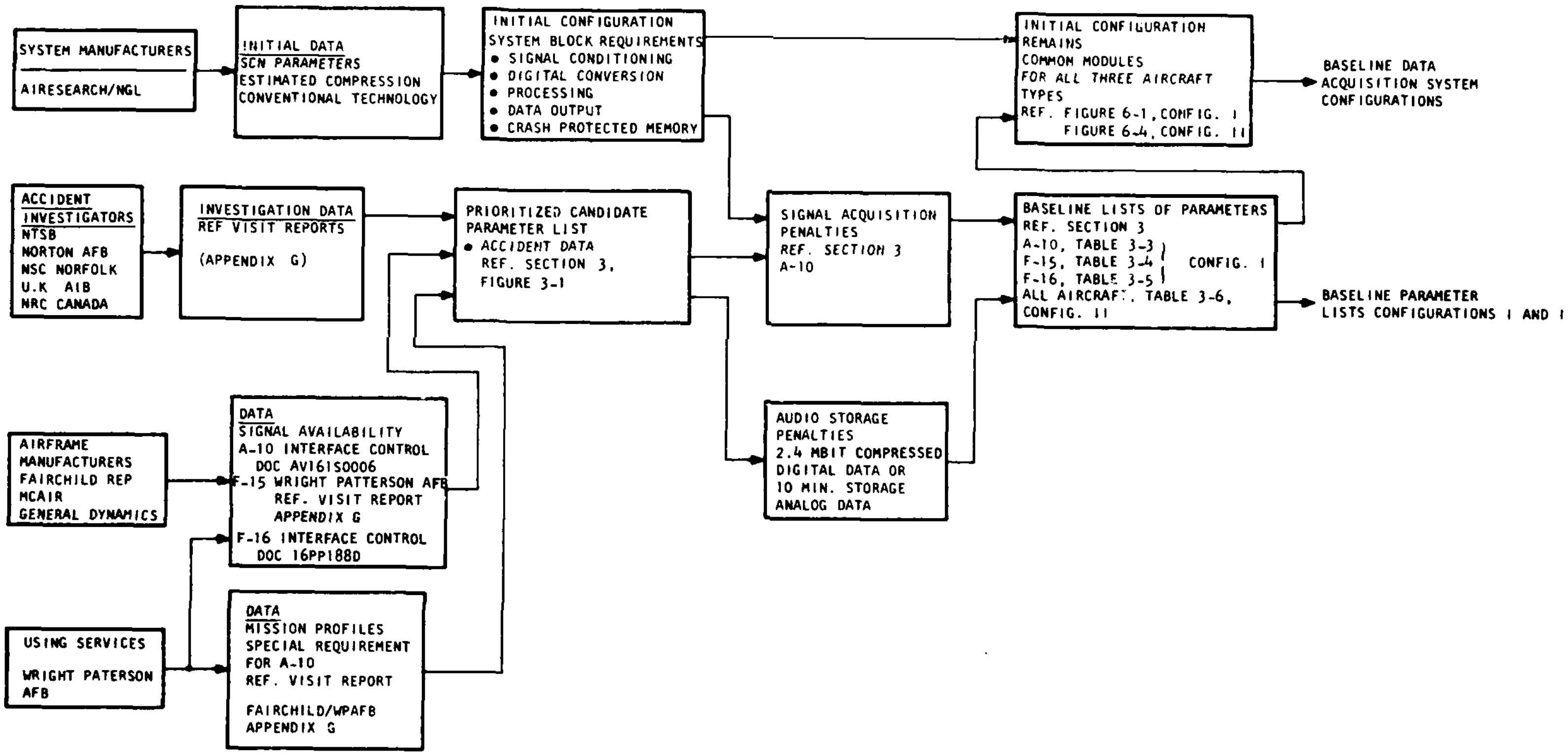

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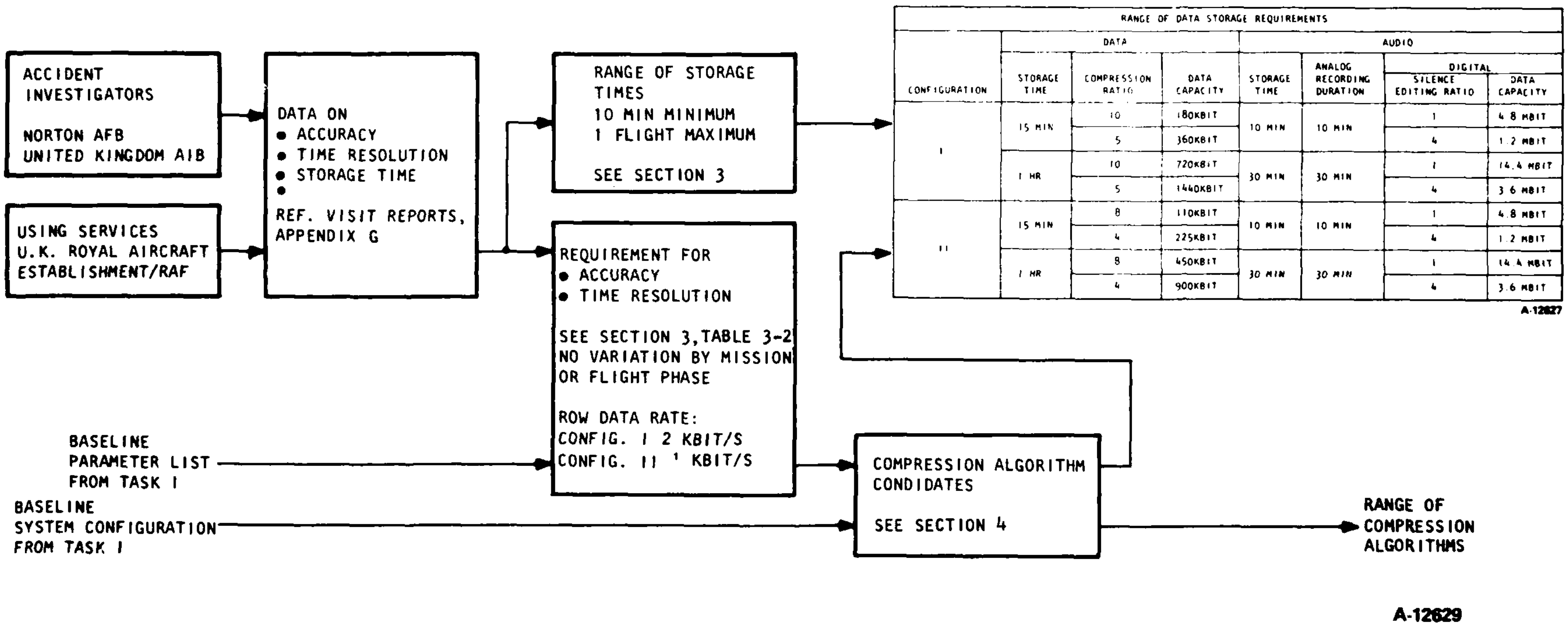
Figure 1-2. Task I



RANGE OF DATA STORAGE REQUIREMENTS

CONFIGURATION	DATA: STORAGE TIME	DATA: COMPRESSION RATIO	DATA: DATA CAPACITY	AUDIO: STORAGE TIME	AUDIO: ANALOG RECORDING DURATION	AUDIO DIGITAL: SILENCE EDITING RATIO	AUDIO DIGITAL: DATA CAPACITY
I	15 MIN	10	180KBIT	10 MIN	10 MIN	1	4.8 MBIT
		5	360KBIT			4	1.2 MBIT
	1 HR	10	720KBIT	30 MIN	30 MIN	1	14.4 MBIT
		5	1440KBIT			4	3.6 MBIT
II	15 MIN	8	110KBIT	10 MIN	10 MIN	1	4.8 MBIT
		4	225KBIT			4	1.2 MBIT
	1 HR	8	450KBIT	30 MIN	30 MIN	1	14.4 MBIT
		4	900KBIT			4	3.6 MBIT

Figure 1-3. Task II

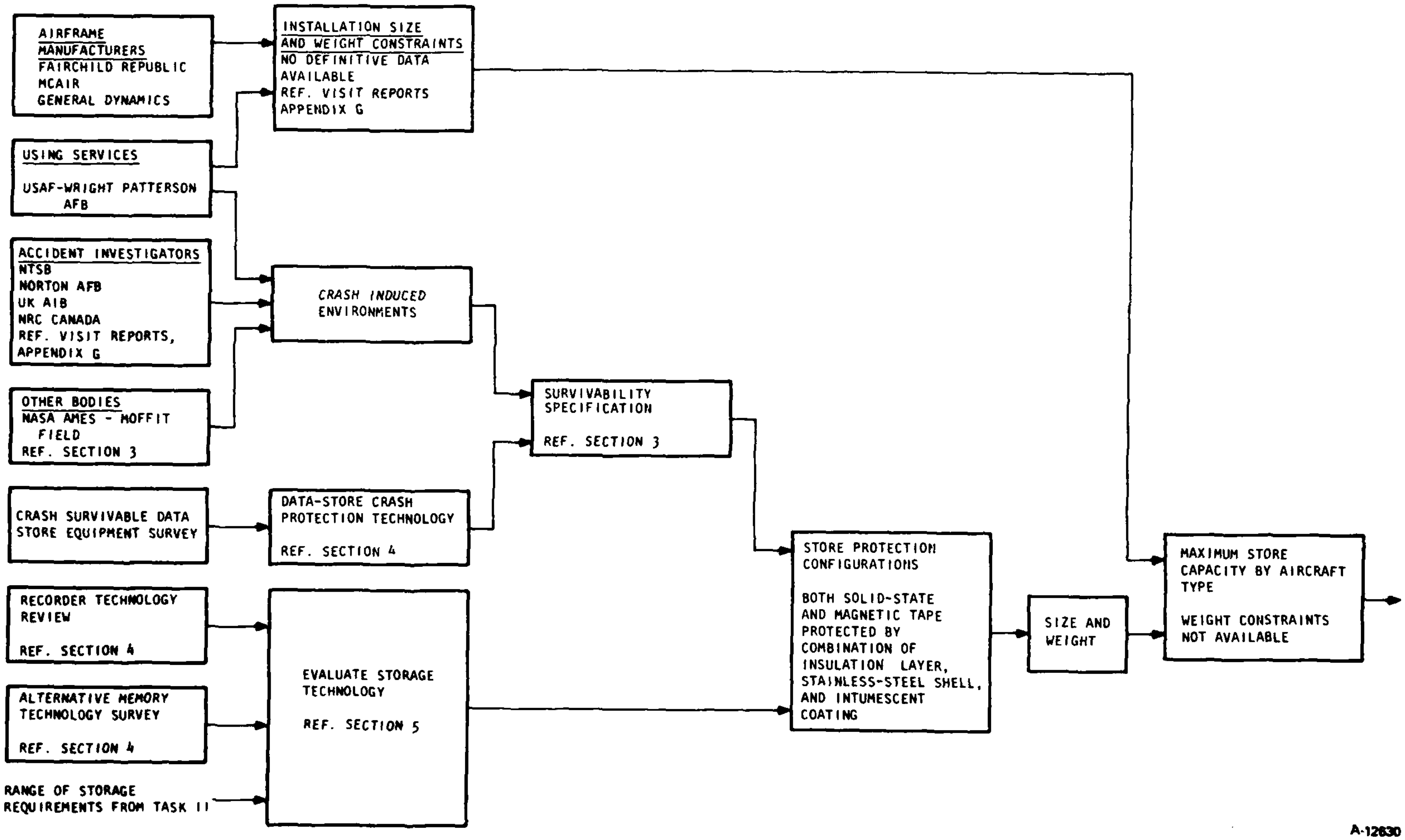


Figure 1-4. Task III

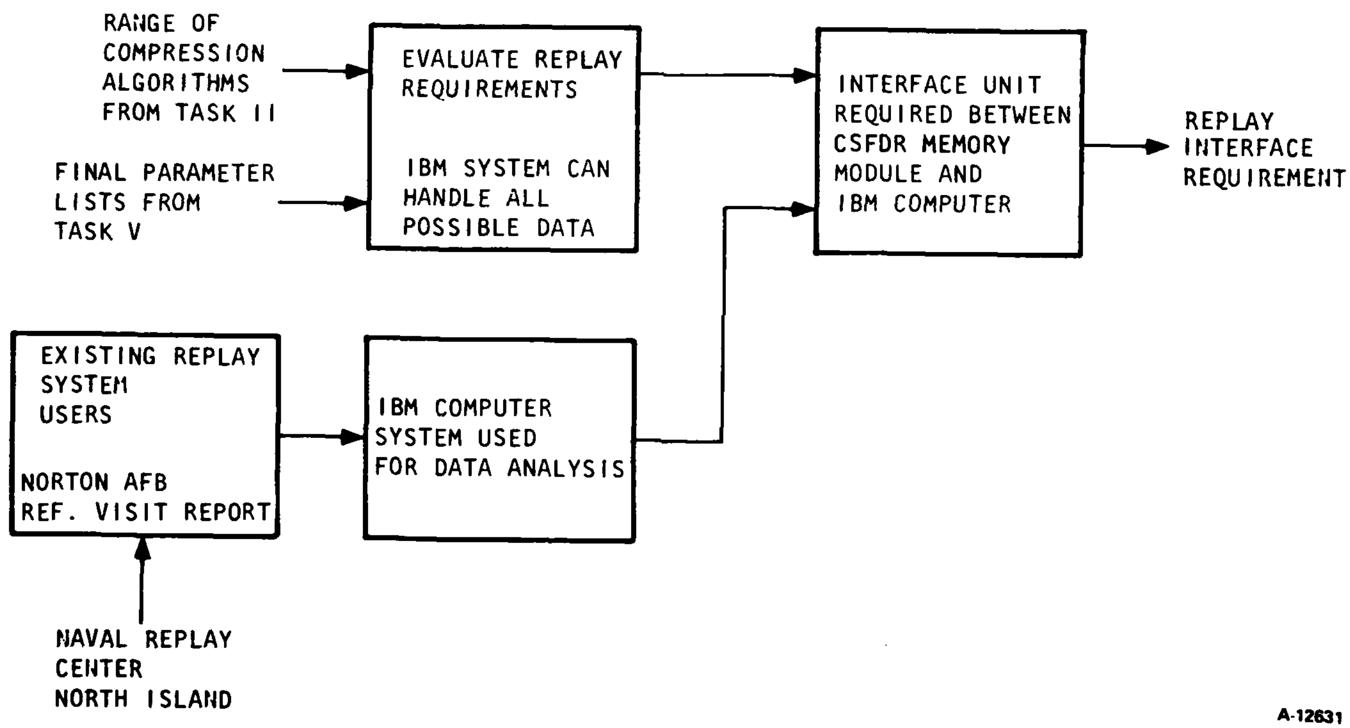


Figure 1-5. Task IV

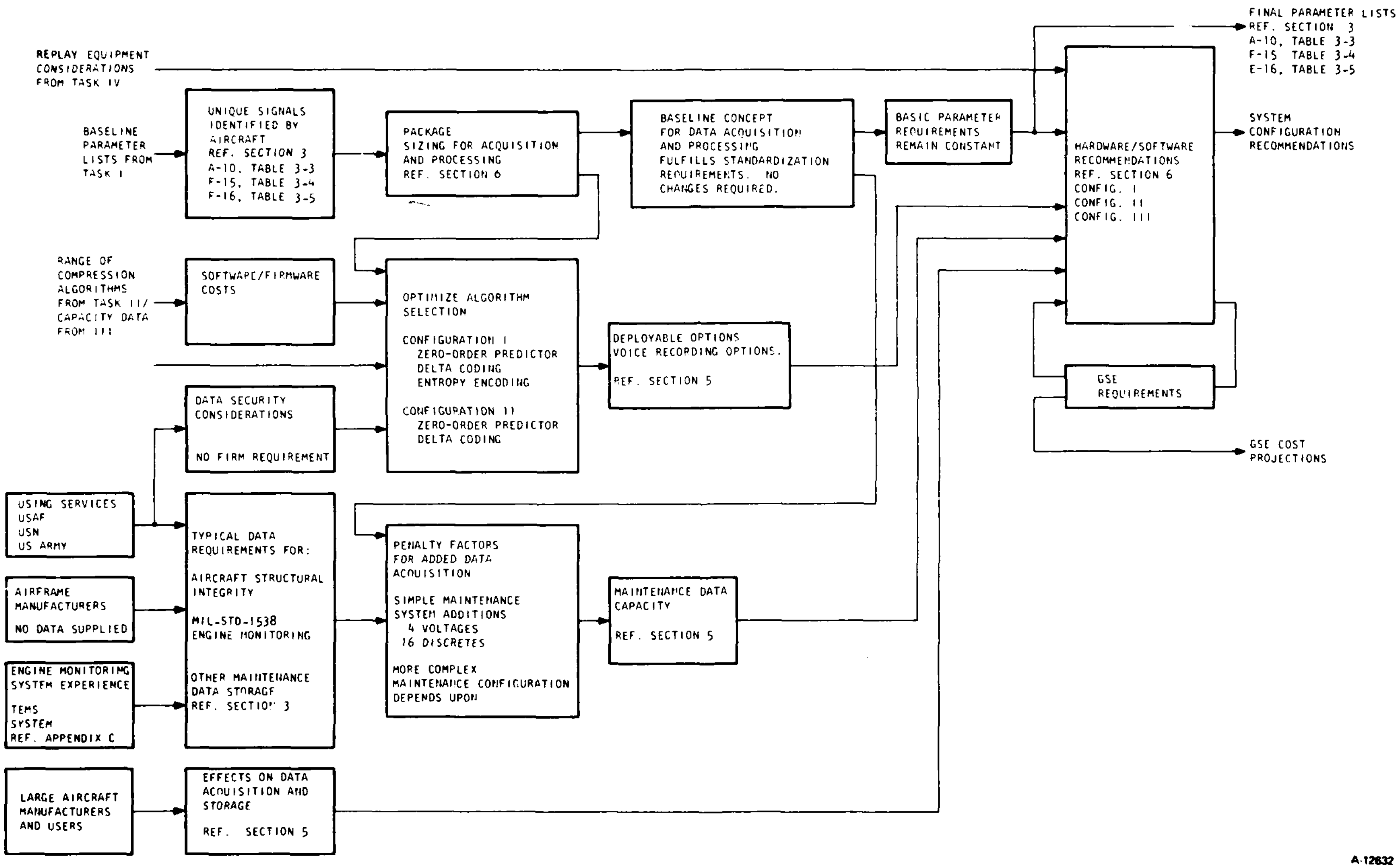


Figure 1-6. Task V

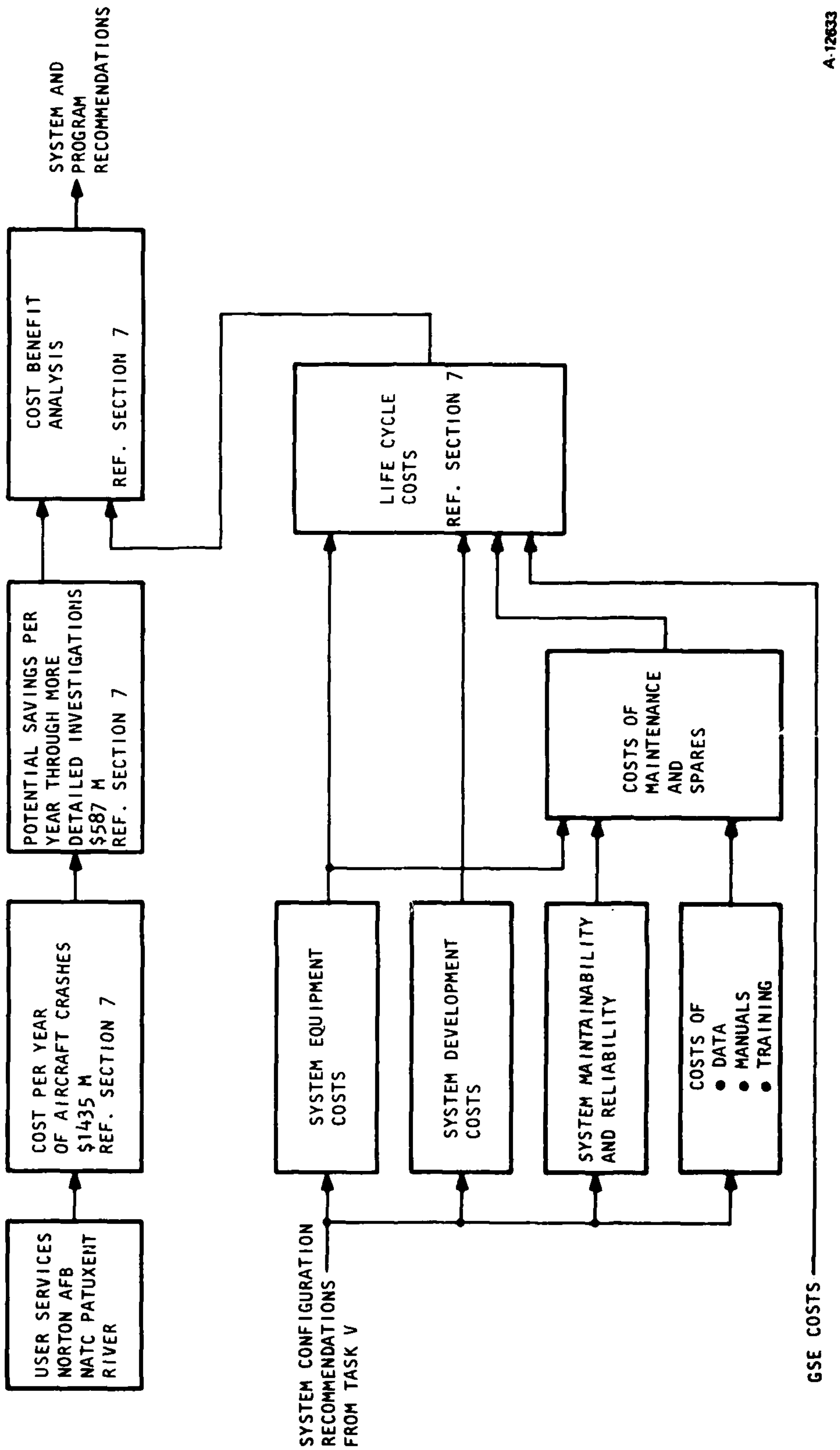


Figure 1-7. Task VI

SECTION 2

NEED FOR PROGRAM

The United States Air Force loses approximately three squadrons of aircraft each year due to accidents. The information from this study indicates that 10 percent of these accidents could be prevented if more timely and precise definition of the cause of each accident were available.

The National Transportation Safety Board (NTSB) states in Safety Recommendations A-78-27 through A-78-29, "Accidents investigation experience with air carrier aircraft has proven that cockpit voice recorders and flight data recorders have been invaluable tools in identifying aircraft design deficiencies, common operational problems, shortcomings in air traffic control systems, and the effects of meteorological phenomena on aircraft performance". The same safety documents cite 194 fatal accidents of air taxi and corporate/executive operations, with the cause undetermined in 34 cases.

A spokesman for the United Kingdom Ministry of Defense, Inspectorate of Flight Safety, stated that in 18 Jaguar aircraft losses the cause was unknown for 9, although it was thought that in most cases the cause was due to failure of the navigation equipment. This spokesman felt that 25 percent of these losses could have been prevented if a crash survivable flight data recorder (CSFDR) had been onboard the aircraft. He also felt that the need for a CSFDR was great for military aircraft of the future, since electrical control system failures and integrated displays do not leave evidence within the wreckage to help determine the cause of the accident. Although no statistics are available for aircraft of this type, the complexity of aircraft has progressively increased over the years. Statistics of Navy/Marine aircraft destroyed in major accidents from 1975 through August 1980 show a distinct trend (see Table 2-1). The percentage of aircraft crashes in which the cause is not determined appears to be increasing in later years. Statistics for aircraft lost in water have not been included as the recoverability of the aircraft could influence the results.

TABLE 2-1

NAVY/MARINE AIRCRAFT CRASH STATISTICS

Year	1975	1976	1977	1978	1979	1980
Aircraft lost on land	52	50	63	53	55	41
Number where cause is determined	51	46	60	43	47	34
Percentage where cause not determined	1.9	8	4.7	18	14.5	17

If a CSFDR were fitted to an aircraft that crashed and the data were available to the investigation board, it is expected that the cost of the investigation would be reduced and confidence in the determination of the cause would be increased.

This recorded data can show deficiencies in pilot training methods, operational procedures, or limitations within the aircraft design, which if corrected could prevent recurrence of similar accidents. Without the availability of the recorded data, these deficiencies might not be discovered; this means that other accidents from the same primary cause are a possibility. A qualified authority in Europe states that there is usually more than one contributing factor in most accidents. He also stated that it is potentially damaging to the reputation of the airline if more than one accident occurs and the cause is determined to be of the same origin.

Details of 818 USAF accidents involving fighter attack and training aircraft since 1976 were obtained from Norton AFB. An analysis of these details indicate that in 21.5 percent of the Class A accidents the cause was not determined, and in 21.5 percent of the other cases, the report was inconclusive as to the cause.

SECTION 3

DEVELOPMENT OF SYSTEM REQUIREMENTS

In order to define the requirements for an optimum crash survivable flight data recorder (CSFDR) system to assist with accident investigation, data from authorities in this field were compiled and evaluated. This information included optimum information that should be recorded, the required accuracies, recording duration, and the memory module survival requirements.

The following paragraphs define the design requirements for CSFDR system and include the rationale for the selection of these requirements.

PARAMETER PRIORITIES

Lists of parameters considered potentially critical in determining the cause of an accident were obtained from several qualified agencies, both in North America and in Europe. To enable a priority to be placed on the possible parameters to be recorded, the parameters contained in each list are given a priority number. This number was chosen by consideration of the relevance to the aircraft being considered in this study, and by the priority placed on the parameter within the list by each agency.

Table 3-1 details the source of each list, the aircraft category for which the list was prepared, and the priority numbers that have been placed on those parameters. Figure 3-1 gives a histogram for the candidate parameters. This enables these parameters to be placed in order of priority so that the importance of each parameter may be assessed when preparing a particular aircraft installation.

It should be noted that for specific aircraft, certain parameters could have particular significance for accident investigation purposes. This cannot be shown in a generalized list.

The primary objective of this study is to determine if a CSFDR system is cost effective for fighter, attack, and training aircraft. Of the six lists (which can be found in Appendix A), two are concerned with commercial and general aviation requirements and consequently have been given the lowest priority number. The parameter list for the F-18A is given the next priority, even though it is a fighter/attack aircraft. This list was prepared with the mode of operation, often from a carrier base, taken into consideration. The other lists were prepared for aircraft of the types to be investigated for this study. All have been given a similar priority rating.

TABLE 3-1

SOURCE DATA OF PARAMETER PRIORITY

Source of Information	Aircraft Category	Priority Number
National Transportation Safety Board safety recommendations A-78-27 through -29, April 1978	List contains 39 parameters in order of preference; however, these are intended for use with multiengined general aviation aircraft	3 units for 11 parameters with highest priority 2 units for next 9 parameters 1 unit for remainder
Statement of Need parameters from CSFDR study requirement	Parameter list prepared by Air Force as requirement for flight data recorders; two categories essential and desirable	5 units for essential parameters 2 units for desirable
Statistical data for F-15, F-16, and A-10 accidents	Presents percentage of accidents for each aircraft type in which each parameter would have been useful in determining the cause	The percentage for each parameter from the three aircraft types are summed and that total divided by 30 to produce the units given to each parameter
U.S. Navy parameter list required for F-18 Hornet	Parameter list prepared for proposed flight data recorder for F-18A	3 units for each parameter
UK specification 10, Civil Aviation Authority, general flight data recorder requirements	General flight data recorder requirement for airplanes with a maximum weight of 12,500 lb or above	2 units for each parameter
List prepared by UK engineering advisor to CAA and Royal Air Force on crash recorders	List prepared for fighter-type aircraft with 4 deg of priority	5 units for highest priorities 4 units for next highest 3 units for next 2 units for remainder

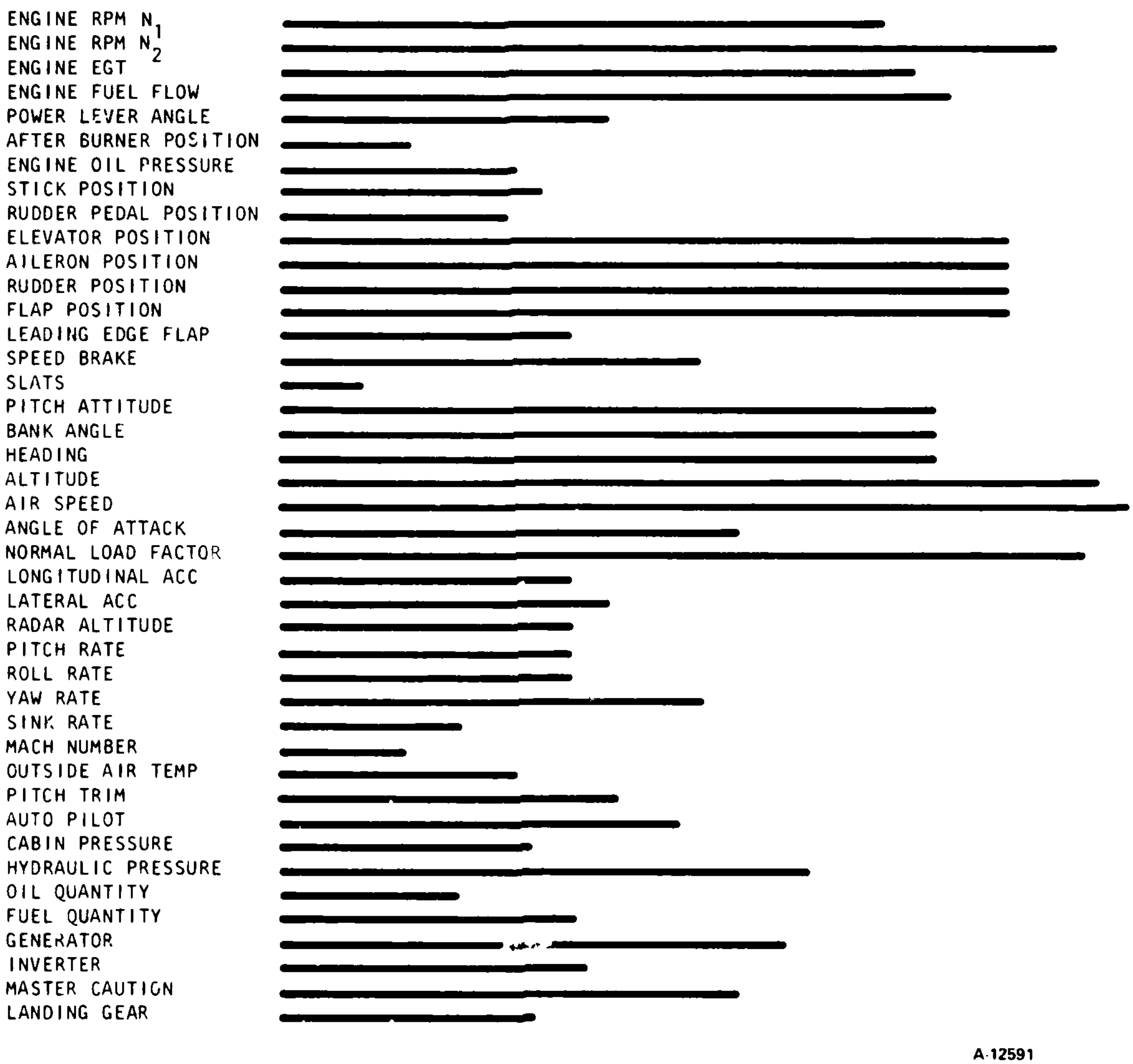


Figure 3-1. Parameter Priorities

The Civil Aviation Authority directive for fitment of a CSFDR states that the objective in the selection of parameters is to obtain the following information:

(a) The flight path of the aircraft

(b) The attitude of the aircraft in achieving that flight path

(c) The basic forces acting upon the aircraft and resulting in achieved flight path, such as lift, drag, thrust, control forces

(d) The general origin of the basic forces and influences, such as navigation information and aircraft system status information

In addition to this data, which will enable a three-dimensional flight path of the aircraft to be produced, information is required to enable determination of the area in which any problem originates. This requires the storage of the following information:

(a) States of major aircraft systems

(b) Events contributing to the aircraft forces

(c) The environmental conditions present at the time

Although Figure 3-1 provides an idea with respect to preparation of the parameter list for a particular aircraft, the requirements listed above should not be neglected, especially if the aircraft has an unusual control configuration.

Audio Recording

One of the tasks undertaken as part of this study was to evaluate the importance and impact of adding the recording of audio to the CSFDR system. All of the personnel surveyed during this study were questioned on their opinion about the recording of audio for accident investigation purposes. The consensus was that for a single-seat aircraft the recording of audio, although useful, was not a maximum priority.

The United Kingdom accident investigation branch felt that a "hot mike" audio input should be recorded to pick up other audible sounds within the cockpit in addition to as the pilots communications inputs. A representative of the United Kingdom Inspectorate of Flight Safety mentioned that the audio recording of the two Tornados that crashed was extremely useful in determination of the cause.

If solid-state storage is to be used for recording of audio information, the audio must be digitized prior to storage. The recording of audio, using even the latest available compression technology with silence editing (see Section 4), requires a memory size of about 2.5 Mbits to store the last 10 min.

At this time and for this application, the additional cost of adding the memory and compression circuitry does not appear to be justified if a solid-state storage module is utilized. This could be modified by the findings of a more detailed investigation into the usefulness of audio or if tri-service standardization is required.

It is possible that the future availability of vocoders, which will allow a higher compression, together with the increased packing density of future memory chips could change this situation.

PARAMETER CHARACTERISTICS

Most of the agencies contacted were surveyed on their views of parameter sampling rates and accuracies required for accident investigation purposes on fighter, attack, and training aircraft. John Sturgeon of the Royal Aircraft Establishment at Farnborough, engineering advisor to United Kingdon Civil Aviation Authority and The Royal Air Force on flight data recorders, provided the only definitive information, which is included in Appendix A.

Information is available for commercial aircraft requirements, but the sampling rates need to be increased for the more maneuverable aircraft being considered. Details of the maximum rates of change to be expected for each parameter on the three aircraft types being studied are included in Table 3-2. From these maximum rates of change and the required accuracy, an estimate was made for the sampling rates that compares closely with those submitted by John Sturgeon (see Appendix B). Norton AFISC/SESD stated each parameter should be accurate enough to monitor normal instrument fluctuations.

NTSB recommendations A-78-27 through A-78-29 provide accuracy requirements for the recommended parameters. With these guidelines, the accuracy for each parameter was determined. The NTSB recommendation also includes a minimum resolution requirement.

Using the maximum rates of change, which could be present under crash conditions, the sampling rates were determined. These were selected so that under normal operating rates of change, the parameter profile could be determined within the accuracy required. Figure 3-2 shows a typical method of determining the parameter profile.

The discussions with accident investigation personnel indicated that in the majority of accidents, the data from the 5 min prior to crash contained the most critical information and should, if possible, be stored uncompressed or stored in such a way that the data is completely reconstructable. It is probable that during the last few minutes prior to crash at least one, if not more, of the parameters will be changing at a rate approaching maximum.

During this critical period, the equipment providing the signals of the important parameters is required to be fully operational and should not be shed if load shedding is necessary. Additionally, equipment that would not be essential for flight but would provide important signals to the CSFDR will be required to change to flight essential.

TABLE 3-2

PARAMETER PRIORITIES ACCURACY AND SAMPLING RATE REQUIREMENTS

	Max. Rate of Change, percent per sec	Required Accuracy, percent	Sampling Rate, per sec	Word Length, bit
Airspeed	4	1	2	11
Altitude	1.6	0.125	8	12
Normal Load Factor	100	0.6	16	9
Engine rpm N_2	20	2	1	8
Elevator Position	100	4	8	7
Aileron Position	100	4	8	7
Rudder Position	200	4	8	7
Flap Position		6	1	6
Engine Fuel Flow	20	2	1	8
Heading	17	0.5	8	10
Pitch Attitude	17	0.5	8	10
Bank Angle	100	0.5	16	10
Engine Egt	50	2	2	8
Engine rpm N_1	20	2	1	8
Hydraulic Pressure		10	1	6
Generator		10	1	6
Angle of Attack	100	1	16	9
Master Caution*	Discretes	--	1	2 x 16
Yaw Rate	17	2	4	8
Pitch Trim	20	5	1	7
Lateral Acceleration		2	8	8
Power Lever Angle	100	2	1	8
Inverter		10	1	6
Fuel Quantity	0.1	5	1 per 16 sec	7
Radar Altitude	25	0.1	16	11
Leading Edge Flaps	100	5	1	7
Pitch Rate	100	2	8	8
Roll Rate	400	2	16	8
Longitudinal Acceleration		2	8	8
Engine Oil Pressure		10	1	
Stick Position	100	4	8	7
Cabin Pressure		10	1	6
Outside Air Temperature		1	1	8
Rudder Pedal Position	200	4	8	7
Sink Rate	50	2	8	8

*Elapsed time count included within stored data.

NOTE: Master caution words to include auto pilot, speed brake, and all cautionary discretes.

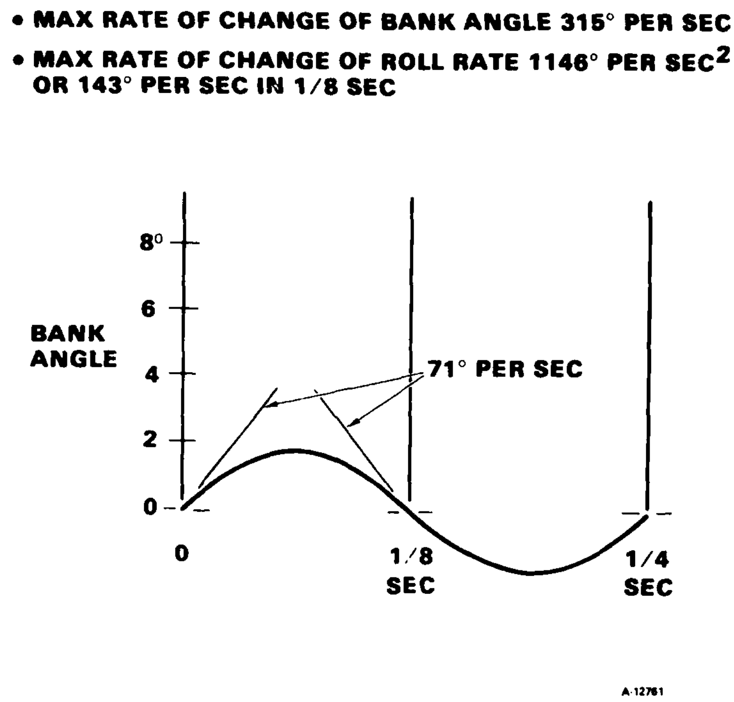


Figure 3-2. Derivation of Sampling Rate for Bank Angle

If an aircraft carrying a CSFDR system crashes in hostile territory, it is possible that information contained within the stored data could be analyzed to determine the operational performance and tactical information. Data encryption devices are available from more than one source, thereby making it possible to scramble the data during the record process while still being able to replay that data if the scrambling code is known.

RECORD DURATION AND SPECIFIC EVENTS REQUIRING STORAGE

The views expressed by the different accident investigation organizations and other personnel involved with accident investigation differ widely with respect to the minimum memory duration required for a CSFDR. The shortest time duration considered necessary is 10 min; the longest is the maximum duration for one complete flight of the aircraft concerned.

The main arguments made for the longer duration are that confidence can be gained with respect to the functional status and calibration of each of the signal inputs to the system. This is primarily achieved by checking the excursions of the parameters during the previous landing and takeoff. If the CSFDR system is organized such as to store data from the preflight control exercising and the takeoff, the majority of experts accepted that 15 to 30 min of memory duration would be adequate. Some considered that if the system also carried out a maintenance function, and if the maintenance storage module were removed after each flight, then the storage of the preflight and takeoff data would not be necessary.

The graph shown in Figure 3-3 depicts an accident recording time distribution, obtained during the course of this study. To ensure its validity a copy was sent to NTSB. Their reply is included in Appendix I, which makes the case for recording of the takeoff and landing prior to the accident, and should include exercising of the controls. In this case only 10 to 15 min of the last data are considered sufficient.

CRASH SURVIVAL REQUIREMENTS

If a CSFDR system is fitted to an aircraft it is the prime requisite that the data storage module survives the accident, such that the data can be extracted and analyzed.

The majority of current crash protected recorders utilize magnetic tape recorders contained within an enclosure that is crash hardened to meet the requirements of TSOC51a. This requirement was prepared for recorders installed in commercial aircraft. For this application, with aircraft that are considerably faster and contain less fuel, the requirement could be too stringent in some areas and not stringent enough in others.

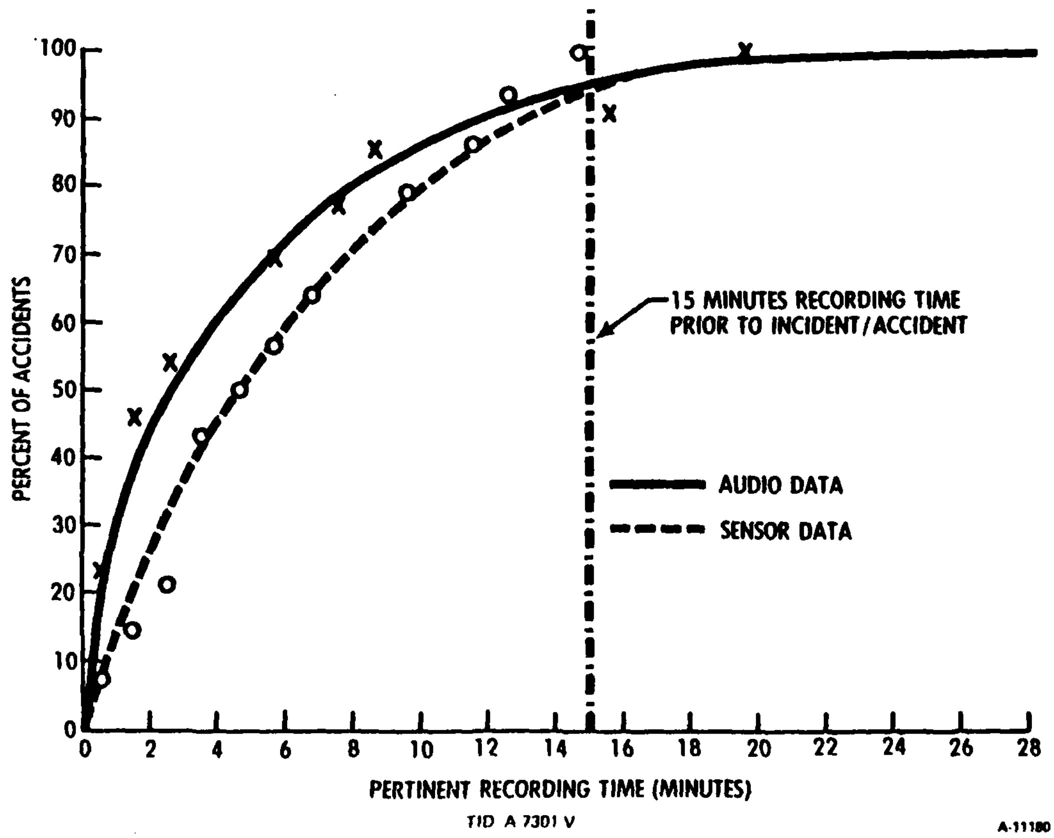


Figure 3-3. Accident Recording Time Distribtuion (Data From National Transportation Safety Board)

Contact was made with Dr. Thomson of the Impact Dynamics Research Facility at Langley, Virginia. Dr. Thomson has extrapolated results obtained from civilian crashes, taking into account details of a typical fighter aircraft structure, to obtain an estimate of the maximum shock to be experienced by any equipment fitted in a fighter that crashes. He estimates the shock to be a maximum of 1000 g with a duration of 35 ms. He expects the shock to be a triangular waveform with linear rise and fall and a rise time of between 20 and 80 percent of the duration. This compares to the TSOC51(a) requirement of 1000 g for a 5-ms half sinewave.

The department run by Dr. John Parker at NASA AMES Moffat Field has carried out tests with fuel fires such that an estimate can be made of the temperatures and duration of fires resulting from an aircraft crash. Joseph Mansfield within this department quoted the following details:

Temperatures measured above a pool fire

at 4.7 ft	1300°C
at 9.4 ft	1360°C
at 18.8 ft	1400°C

1/4 in. depth of fuel will burn in 1 min on a flat surface. Fuel flowing at 150 gallons per minute will produce a fire of 18 ft radius, 600 gallons per minute 35 ft radius, 2400 gallons per minute 70 ft radius. For the aircraft being considered the maximum fuel carried without external tanks is less than 1800 gallons. If this leaks at a rate of 150 gallons per minute it will produce a fire lasting for just over 12 min. If there is a severe impact, fuel is likely to leak at a higher rate than this. If the impact causes a lower fuel leakage rate the radius of the fire will be smaller and will probably not engulf the tail of the aircraft where the storage module is expected to be installed.

Even if the storage medium is crash hardened it is advisable to install it within the aircraft in a position where the crash conditions are likely to be least severe and where the unit is most likely to be easily recovered from the wreckage. It is universally accepted that the tail section of the aircraft more frequently survives an aircraft crash than any other section. All of the personnel contacted during the course of this study recommend installation as far aft as possible, away from the fuel tanks and not in front or close to any heavy structure or objects such as engines. This is likely to ease the recovery of the storage module from the wreckage.

The alternative to crash hardening the storage module such that it will survive an aircraft crash is to ensure that the module does not end up in the crash or any resultant fire. In an attempt to achieve this, several different types of ejectable or deployable modules have been produced over the years. The only systems that claim any degree of success use one of two basic methods: either pyrotechnic means of ejection or the aerodynamic properties of an airfoil.

Due to the obvious danger associated with pyrotechnic systems this can be disregarded unless the storage module were attached to the pilot's ejection seat. This would present an optimum solution if it were certain the pilot would or could eject prior to the crash. Out of 818 U.S. Air Force fighter attack and trainer aircraft involved in accidents since 1976, 325 aircraft were lost and in only 192 cases did the pilot eject.

The airfoil system theoretically deploys on impact such that its aerodynamic properties cause it to fly away from the immediate crash area. The drawbacks of this type of system are: (1) there is a high cost of developing an airfoil for each aircraft type; (2) modification of the aircraft structure would be required to fit the airfoil; (3) there is a possibility of inadvertent deployment; (4) and when deployed the storage module could still end up in the crash area, particularly in a fire area.

Present airfoil design is such that the device will float in water. Deployment in general is initiated by frangible switches that break as soon as the aircraft structure is deformed. In addition, a crash position indicator is fitted within the airfoil.

The location and recovery of an aircraft that crashes into water is extremely difficult and expensive. If the crashed aircraft contained a CSFDR, the protected memory module would require to be found and retrieved. This would be difficult unless the memory module were within an airfoil that was deployed.

Only if a large proportion of crashes occur in water does this become a viable solution. Of the 818 accidents analyzed, less than 6.2 percent crashed in water. For this reason, the use of a deployable memory module is not recommended. However, consideration should be given to the installation of an underwater locator beacon, to aid with the location of the crash protected memory module. Due to the cost and weight of such devices, and to the low proportion of aircraft that crash into water, such devices are not considered generally warranted.

LOGISTIC CONSIDERATIONS

A CSFDR system provided for aircraft accident investigation purposes will hopefully never be used on that particular aircraft, since it is provided only to make information available about a flight in which there was an incident or accident, to assist with determination of the cause. It is important that the system be fully functional if this incident or accident occurs. Built-in test can provide a limited degree of confidence that the system is functioning. The failure of an individual signal source, not utilized and checked by other aircraft equipment, could remain undetected unless periodic checks are made on the total CSFDR system including the signal sources.

It is possible for the processor to detect if any of the signals has deviated outside its normal range where there is a dircet interrelationship between two or more parameters so that between rudder pedal position and rudder position any discrepancy can be flagged. For parameters such as the discretes and hydraulic pressures, no practical method of determining if the sensor has failed is available.

It is not practical to carry out periodic calibration checks on each parameter, except possibly during a major aircraft maintenance check. If a periodic replay is made of data stored during a flight, and the stored data includes the pretakeoff checks and takeoff data together with the last landing, analysis of the data should indicate if any parameter is not functioning correctly.

With the use of a solid-state storage medium, where the memory can deteriorate with the number of erase/write cycles, it is necessary to check the integrity of the store periodically. With the Intel E^2 store, this is possible by carrying out a soft erase and then reading the data still contained in the store.

Since the crash protected storage module is likely to be positioned in a relatively inaccessible location in the aircraft, periodic review of the data would make it necessary to milk that module in place. As part of the life-cycle costing, the provision of flight line test units at each of the aircraft locations has been included. These flight line test units will enable a qualitative check on the memory module to be carried out. Each will contain a cartridge memory onto which the storage module can be milked, with provision to input header data for the particular aircraft and date. Each cartridge will have the capacity to accept data from several aircraft.

It is assumed that the analysis of the data to ensure correct operation of the CSFDR system will be carried out at intermediate repair facilities. Failure isolation and repair for all except the processor circuit card is assumed to be carried out at the same facilities, and stand-alone test units will be provisioned.

STANDARDIZATION

One of the objectives of this study was to determine both the requirements and potential for standardization on a CSFDR system. Standardization was to be investigated for tri-service application for all aircraft types with a similar basic function as well as for different functional aircraft types. The primary objective was to produce an optimum configuration applicable for all USAF fighter, training, and attack aircraft and then to determine the impact on that configuration for tri-service applications and for bomber and transport aircraft.

The major differences to be encountered from one aircraft type to another that have the same basic functions lie in the available signal sources for each of the parameters forming part of the basic requirement. Provision has been made within the proposed design to accommodate these variations (see Section 6).

For the tri-service application, the requirements and basic differences in operation and aircraft type have to be considered, together with any specific requirements of each service. A large proportion of the U.S. Navy flights are carried out over water. Of 557 aircraft lost between 1975 and mid-1980, 43 percent were lost in water. In consequence they require that the data storage module for the CSFDR be deployable and also contain a crash position indicator (CPI). This is to ensure both that the position of the wreckage is identified and the recording can be recovered without the high cost of recovery from the wreckage.

The U.S. Navy also include the requirement that audio from the pilot's communications system should be stored. To accommodate these requirements if not fitted, a separate storage module could be utilized for the audio, and both this module and the module provisioned for data could be fitted within a deployable airfoil. Space provision could be made for fitment of the single circuit card required to condition and compress the audio data within the processing unit. When vocoders and the higher capacity storage chips are available, it would be practable to provision two identical storage modules, one for audio and one for the digital data. Alternatively, if the storage module were developed to have adequate capacity for audio, both could be incorporated in a common store.

The majority of U.S. Army aircraft are helicopters. A CSFDR system for helicopter applications would require the recording of different parameters. These parameters are likely to be monitored by transducers or equipment producing signals with the same basic ranges as those considered for this program, and the required sampling rates are likely to be of the same order. To accommodate this within the system will require at least the change of system firmware.

For use with bomber and transport aircraft there are several considerations to be taken into account:

(a) In general, bomber and transport aircraft have four engines. Even to store the same parameter information as for fighters and attack aircraft, the number of parameters to condition from the engines will be doubled. This would require one additional circuit card.

(b) Due to the flight duration of these aircraft and the possibility that a problem with an engine could contribute to the cause of an accident even though it happened some time before, the duration of recording required is considerably longer.

(c) The sampling rates determined for some of the flight profile and flight control parameters for a fighter/attack aircraft are likely to give a higher than necessary resolution if utilized on a bomber-transport aircraft.

From the above, it is not considered cost-effective to have one CSFDR system tailored for both applications, although the basic design of the acquisition system modules could remain the same.

MAINTENANCE RECORDING

All of the personnel responsible for maintenance recording and collection of data for performance work, as well as the airframe manufacturers consulted, considered it would be advantageous if the CSFDR system included any required maintenance recording function. For configuration III (see Section 6), the study objective is to evaluate the impact on the design of adding parameters associated with structural integrity, turbine engine health, and flight control monitoring.

There are several programs sponsored or carried out by the USAF that require some form of data acquisition and recording, each with a different objective. There are programs concerned with engine health and performance, with the objective to improve system support costs and aircraft operational availability. Other programs are concerned with obtaining information relating to fracture mechanics, structural strength requirements for future aircraft, and the Aircraft Structural Integrity Program (ASIP).

Included in the parameter list table derived for the CSFDR (see Table 3-2) are many of the parameters necessary to be processed and recorded for the above functions. The numbers and types of additional parameters required to be processed depend to a large extent on the aircraft configuration, engine type, and the depth of maintenance to be undertaken. The size of the storage module required for maintenance data also depends on this and to a large extent upon the degree and type of data compression to be undertaken.

Currently, the U.S. Air Force is evaluating a turbine engine maintenance system (TEMS) fitted to the A-10 aircraft. This system processes 13 parameters from each engine and 7 airframe inputs. The degree of data compression is such that only relevant information is stored and an 8 kbit store is adequate. To accommodate this type of system within the configuration I approach would involve the addition of one circuit card for the additional signal interface and conversion and a nonvolatile memory chip that could store data for post-flight analysis. The TEMS system has a suitcase display to detail required maintenance actions. This would also have to be included with the system and could incorporate the capability to transfer and evaluate crash data on a periodic basis, as discussed above.

Another program carried out over the last few years for the F-101 engine is central integrated test subsystem evaluation (CITSE). In this, the parameters to be processed and recorded include those for engine performance trending and failure prediction. The parameter list is included in Appendix D and includes approximately 55 analog parameters per engine and 20 discretes. To include the capability to add this to a CSFDR would impose a large weight and size penalty to the basic CSFDR processing unit. If it were intended that every system fitted would contain both functions this would almost certainly be the cost-effective solution. This is thought unlikely to occur and therefore it is recommended that any CITSE requirement would be met with a separate system.

Many other engine health monitoring systems with various degrees of complexity have been suggested and in some cases developed. The large majority of these systems utilize a tape transport as the storage module and only process approximately 12 additional parameters for each engine over those required for the CSFDR system.

In addition to the parameters included within those considered necessary for a CSFDR system, aircraft flight control monitoring is likely to require to record or monitor only a limited number of parameters. These will to a large extent depend upon the particular aircraft flight control systems. When signals are to be monitored from any of the flight control systems, particular attention will be required with respect to the isolation of that signal source to prevent interference or cross coupling.

For the aircraft structural integrity program (ASIP), very few of the parameters are not within the parameter list for the CSFDR system. The data is currently recorded at a rate of 1920 bits per second with 240 words of 8 bits. No data compression is carried out on the airborne equipment. This would then require a storage capacity of approximately 14 Mbits for a 2-hr flight. With the processing capability anticipated for the CSFDR system, it is expected to carry out some compression on the data.

From the above it can be seen that there is no definitive specification with respect to the required storage capacity, processing capability, or signal conditioning for the addition of a maintenance recording function.

A median number of 30 additional parameters to be processed and a tape transport that can store up to 13 Mbits of data with an extremely low error rate, necessary if data compression is utilized, would be expected to be representative of most combinations likely to be required.

SUMMARY OF SYSTEM REQUIREMENTS

The rationale in the production of the prioritization of the parameter lists is given in Parameter Priorities (Section 3). The sampling rates and word lengths considered necessary to provide the accuracy and resolution required for accident investigation are given in Table 3-2.

For Configuration I, which is required to record the maximum number of flight parameters, it is preferable to process and store all of the parameters listed. Some of these parameters have a higher priority for accident investigation than others. When preparing the installation design for a particular aircraft, the priority of each parameter should be taken into account when the parameter cannot be recorded without installing a new transducer.

All those parameters listed down to pitch trim (shown in Figure 3-1) should always be made available for processing and storage and those below depend upon their relative cost and priority.

For some of the three aircraft to be taken as representative for this study, certain of the parameters contained within the parameter listing are not available, while other signals from which the same information can be obtained are available. In the case of pitch rate and roll rate, it is possible to obtain this information from the pitch attitude and bank angle data. In the case where the rate signals are not available, the sampling rate, would be increased for the two attitude parameters such that the rate information can be computed with sufficient accuracy and resolution. This would in turn have advantages when delta encoding and compression are used, since under normal flight conditions a higher compression would be possible.

For the A-10 the normal load factor and lateral and longitudinal acceleration signals are not available; however, the X, Y, and Z velocities are present on the 1553 data bus. In this case, these signals would be recorded instead. Where a fuel quantity signal is not available and the bingo discrete is present, this will be recorded.

Parameter lists with details of those parameters where it is recommended to install transducers for configuration I are given in Tables 3-3 through 3-5 for each of the three aircraft being considered.

From Record Duration and Specific Events Requiring Storage (Section 3), the required storage duration is a minimum of 15 min if the preflight data is recorded, giving some degree of confidence in the integrity of each signal stored. Although the information directly pertaining to an accident will be contained within this 15 min of stored data, most of the investigation authorities expressed a desire to have recorded some prior data, to enable an assessment of the way in which the aircraft was handling before the onset of problems. For this reason, a storage duration of 30 min is recommended, in addition to the storage of preflight information.

The determination to include the recording of audio depends to a large extent upon the type of memory module to be utilized and its cost in terms of both size and price. Opinion is divided as to the degree of information obtainable from audio, if it were decided that the memory module for data would be a tape recorder, the additional cost of recording audio would be sufficiently low to warrant its inclusion.

In general, the European accident investigation agencies are in favor of recording cockpit audio in addition to the pilots voice communication. The British Accident Investigation Branch utilize the cockpit audio with spectrum analysis to indicate operation of switches and actuators.

For the type of aircraft being considered with the high-ambient noise level, additional evalution is required prior to making any decision as to whether this should be included as a requirement.

Tri-Service Considerations

If either of the configurations I or II are to be produced for installation by the three services, the basic requirement could be modified.

The Naval requirements include both deployability of the storage module and audio. To be applicable for tri-service use, the data acquisition and processing unit would be the same but include space provision for an audio circuit module unless required for general use. Only the audio circuit module and exchange of the firmware module would be required to make that unit applicable for Naval use. The memory module could then be installed in an airfoil instead of within a crash hardened container.

The configuration I requirement for a data acquisition and processing unit has the following minimum signal input capability:

Synchros	9
Dc Inputs	10

TABLE 3-3

A-10 PARAMETERS FOR CONFIGURATION I

	Signal Type	Word Length	Sampling Rate
Airspeed	1553	11	2
Altitude	1553	12	8
Velocity Y	1553	9	16
Engine rpm N_2	0 to 5 v	8	1
Elevator position	New transducer	7	8
Aileron position	New transducer	7	8
Rudder position	New transducer	7	8
Flap position	0 to 1 v	6	1
Engine fuel flow	-	8	1
Heading	1553	10	8
Pitch attitude	1553	10	16
Bank angle	1553	10	32
Interturbine temperature	20 to 40 mv	8	2
Engine rpm N_1	Tacho	8	1
Hydraulic pressure	Synchro	6	1
Generator	-	6	1
Angle of attack	1553	9	16
Master caution	-	16 x 2	1
Velocity, Z	1553	8	8
Power lever angle	New synchro (TEMS)	8	1
Inverter	-	6	1
Radar altitude	1553	11	16
Oil pressure	Synchro	6	1
Outside air temperature	1553	8	1
Speed brake		7	4
APU rpm	0 to 1 v	8	1
APU EGT	0 to 1 v	8	1

TABLE 3-4

F-15 PARAMETERS FOR CONFIGURATION I

Parameter	Source	Word Length	Sampling Rate, per sec	Remarks
Airspeed	1553	11	2	
Altitude	1553	12	8	
Normal load factor	1553	9	16	
Engine rpm N_2				
Stabilator position				
Aileron position	Synchro*	7	8	
Rudder position	Synchro*	7	8	
Flap position	0 to 10 vdc	6	1	
Engine fuel flow	Synchro	8	1	
Heading	1553	10	8	
Pitch attitude	1553	10	8	
Bank angle	1553	10	16	
Engine FTIT	Low level dc	8	1	
Engine rpm N_1	Tachometer	8	1	
Hydraulic pressure X3	Synchro	6	1	
Generator X2	MIL-STD-704	6	1	
Angle of attack	1553	9	16	
Master caution	Discrete	2 x 16	1	
Yaw rate				
Pitch trim				
Lateral acceleration				
Power level angle				
Inverter				
Fuel quantity	1553	7	1 every 30 sec	
Radar altitude				
Leading edge flaps				
Pitch rate				
Roll rate				
Longitudinal acceleration				
Engine oil pressure	Synchro	6	1	
Stick position				
Cabin pressure				
Outside air temperature				
Rudder pedal position				
Sink rate	1553	8	8	
Information of signal source availability still not received on above parameters left blank.				

*These are only on 20 percent of aircraft, but wiring is available.

TABLE 3-5

F-16 PARAMETERS FOR CONFIGURATION I

Parameter	Source	Word Length	Sampling Rate, per sec	Remarks
Airspeed	1553	11	2	
Altitude	1553	12	8	
Normal load factor	1553	9	16	
Engine rpm N_2	0 to 5 vdc	8	1	
Elevator position	LVDT*	7	8	
Flaperon position	LVDT*	7	8	
Rudder position	LVDT*	7	8	
Engine fuel flow	Synchro	8	1	
Heading	1553	10	8	
Pitch attitude	1553	10	16	
Bank angle	1553	10	16	
Engine FTIT	Dc	8	2	Planned Mod
Engine rpm N_1	Tachometer	8	1	
Hydraulic pressure X2	Synchro	6	1	
Generator X2	MIL-STD-704	6	1	
Angle of attack	1553	9	16	
Master caution	Discrete	16 x 2	1	
Yaw rate	1553	8	4	
Pitch trim				
Lateral acceleration	1553	8	8	
Power lever angle	Pot 0 to 10 v*	8	1	
Inverter X4				
Fuel quantity	0 to 5 vdc	7	1 every 30 sec	
Radar altitude	1553	11	16	
Leading edge flaps	0 to 10 vdc	7	1	
Pitch rate	1553	8	8	
Roll rate	1553	8	16	
Longitudinal acceleration	1553	8	8	
Engine oil pressure	Synchro	6	1	
Stick force	LVDT	7	8	
Cabin pressure				
Free air steam temperature	1553	8	1	
Rudder pedal position	LVDT	7	8	
Vertical velocity	1553	8	8	

*These parameters fitted for ASIP and are only on 18 percent of aircraft. The wiring is in all aircraft.

Tachometer inputs (0 to 80 Hz, 3 phase)	4
Ac ratio	5
Dc ratio	1
Discretes	32
1553 serial data bus (dual)	1
Audio	(optional, 1)

The unit must be programmable to control as a minimum the sampling rates detailed in Tables 3-3 through 3-5 for the A-10, F-15, and F-16.

The configuration II requirement for a data acquisition and processing unit has the following minimum signal input capability:

Synchro	2
Dc inputs	3
Tachometer inputs	4
Ac ratio	3
Dc ratio	1
Discretes	16
1553 serial bus (dual)	1

The unit must be programmable to control as a minimum the sampling rates detailed in Table 3-6.

The memory module shall store a minimum of 30 min of data for configuration I, and if the audio option is added, 10 min of audio.

For configuration II the memory module shall store at least 15 min of data. The recommended parameter list is given in Table 3-6.

Configuration II calls for low development cost and the lowest practical investment cost while still providing at least the minimal parameters for accident investigation.

When determining the parameter list for this configuration the objective in the selection of parameters should be taken into account while utilizing the priority list.

TABLE 3-6

PARAMETER LIST FOR CONFIGURATION II

	Sampling Rate, per sec	Word Length, bit
Airspeed	2	11
Altitude	8	12
Normal load factor	16	9
Engine rpm 2	1	8
Elevator position	8	7
Aileron position	8	7
Rudder position	8	7
Flap position	1	6
Heading	8	10
Pitch atitude	8	10
Bank angle	16	10
Master caution	1	16
Power lever angle	1	8
Total raw data rate 860 bits per sec		

The parameters for accident investigation are selected to enable determination of the following:

(a) The flight path of the aircraft

(b) The attitude of the aircraft in achieving that flight path

(c) The forces acting upon the aircraft and resulting in the achieved flight path (lift, drag, thrust, control forces)

(d) The general origin of the basic forces

Other parameters are recorded to enable any problem to be pinpointed more accurately.

In producing the parameter list (Table 3-6) for this configuration it was considered that where signals were not available for monitoring elevator, aileron, and rudder position these should be installed. Signals are available on the A-10, F-15, and F-16 to provide the rest of the information considered essential.

Special Considerations for A-10

The A-10 operates the majority of its missions at low level and is intended as a front line close support aircraft. The aircraft design is such that it will have the best chance of survival within its expected environment. The aircraft contains foam-filled fuel tanks, which will hold up to 10,700 lb of fuel.

In the event of a crash it is likely that the fuel will escape from these tanks slowly. Any resultant fire is likely to be small and for a relatively long duration. With a crash survivable storage module located in the tail area it is probable the fire would not reach that location. It is therefore recommended that crash protection be to the same level as the other aircraft.

Included within the master caution portion of the parameter list shown in Table 3-3 are all of the cautionary discretes, the slat position discretes, the landing gear discretes, and bingo output. Due to the potential within this aircraft for operation of the APU while airborne, these signals are included within the parameter list.

The general priority parameter list shown in Table 3-2 includes normal load factor and lateral and longitudinal acceleration. These can be obtained from the velocity X, Y, and Z signals. The three attitude rates that are not currently provisional on the aircraft have been left out of the parameter list. Pitch and roll rate can be computed from the pitch attitude and bank angle signals. It is believed that the cost of installing a transducer to monitor yaw rate does not warrant its inclusion. For the list shown, the raw data rate into the signal processor is 1608 bits/sec.

Crash Survival Requirements

From the Crash Survival Requirements portion of Section 3, the shock conditions likely to be experienced in a crash of a fighter, attack, on training aircraft exceed those of TSOC51a in terms of the duration of the shock. Calculations indicate that if the memory module is not shock mounted, the effects of this will be negligible.

We were unable to obtain any special information relating to the penetration forces likely to be encountered in the event of a crash. All people questioned considered that the TSOC51a test requirement was adequate.

The information obtained with respect to the duration and intensity of a fire resulting from a crash indicate that the test requirement could be modified to increase the temperature and decrease the duration. This does not consider the case of a recorder not directly in the fire, which in this case could last for the 30 min of the TSOC51a test.

With the advent of the new types of material being used for thermal protection, such as the intumescent coatings, this could present a problem. We would advocate the testing of the memory module data retention after testing to TSOC51a with a further fire test at a lower temperature if ablative or intumescent materials are utilized; this temperature should be at or about intumescent temperature.

SECTION 4

AVAILABLE TECHNOLOGY

SIGNAL CONVERSION AND CONDITIONING

The analog signals generated by the various transducers need to be converted to a common signal format. There are some parameter signals that will be converted directly to a digital format, such as the tachometer and discrete signals.

Converting the signal to a common format makes the management of the data easier. The types of signals that will be accepted as inputs are listed below:

(a) Synchros

(b) Linear variable differential transformer

(c) Tachometer

(d) Ratiometric

(e) Dc differential, bipolar and unipolar

(f) Discretes

Synchro Conversion

Converting synchro signals to a digital format can be achieved by a number of different methods. Hybrid devices are available that convert a synchro signal directly into a digital word. These hybrid devices incorporate a number of different methods such as successive approximation, harmonic bound oscillators, and real-time trigonometric converters. They have high accuracy and good stability. They have the disadvantage of being expensive and would probably be single-sourced as the units are highly complex and generally proprietary hybrid devices. The more cost-effective method is to design the demodulators using discrete components. For all methods the synchro signal must be converted to its corresponding sine and cosine components.

The conversion can be done by using either a Scott-T-configured transformer, which tends to be bulky but has a very good common mode isolation characteristic, or an equivalent resistor network. The resistor network has the advantages of being compact, having a high input impedance, and having a preferential failure mode that is open circuit.

A typical example of a conditioning circuit is shown in Figure 4-1 and these sampling methods have good characteristics. The ideal time to sample the waveform is during the peak of the carrier wave, so that the modulated carrier wave will produce the largest signals with respect to noise, drift, quadrature, and other imperfections in the measuring circuit.

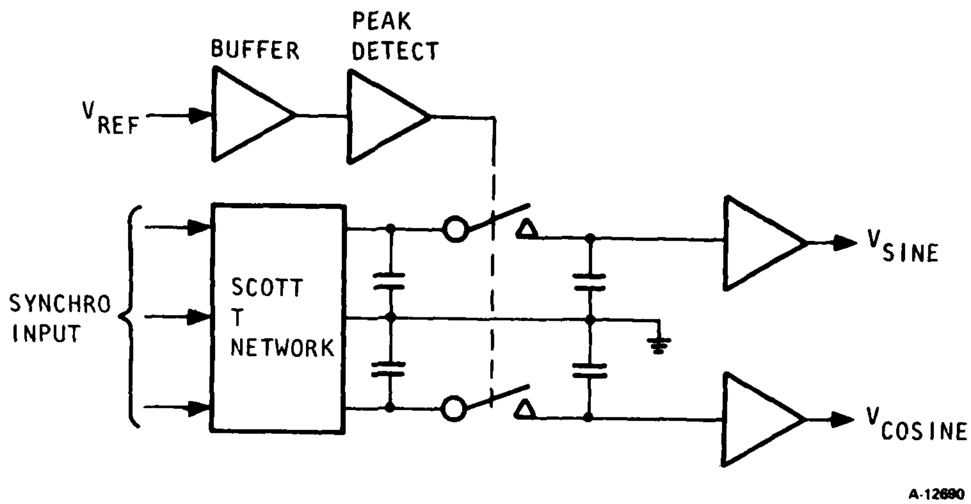


Figure 4-1. Sampling Synchro Conversion

The sampled signal is then converted to digital words using the system analog-to-digital converter; these correspond to the sine and cosine components. The arctangent conversion is then carried out by the microprocessor. It is important that the signals are sampled as synchronously as possible to reduce the error.

LVDT Signals

Linear variable differential transformer (LVDT) signals can be converted to a dc signal using various methods, the two most common methods are discussed below.

Synchronous demodulation is shown in Figure 4-2. The signal from the LVDT is buffered and then demodulated. The LVDT reference signal is used to switch the demodulator. The output from the demodulator is then filtered to remove any ripple and noise. The advantages of this method are that it has high stability, high gain, and requires only a two-wire output from the transducer.

The second method converts the ac signal to dc using a diode discriminator. The signal is smoothed using a low-pass filter. The resultant dc signal is then amplified. This method requires a three-wire input and it has relatively low sensitivity. The main advantage of this method is that it requires no reference signal.

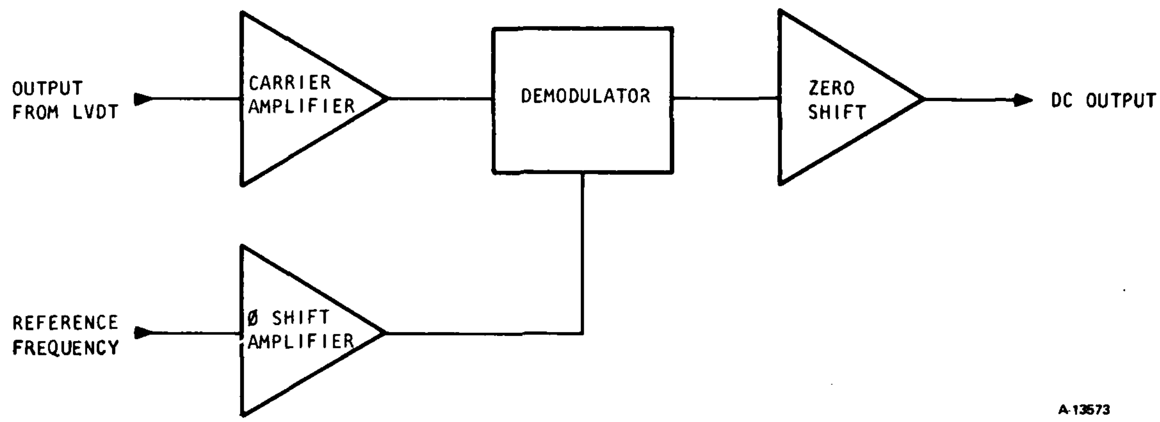


Figure 4-2. Linear Variable Differential Transformer Synchronous Demodulation

Dc Signals

Dc signals are handled with relative ease and only require scaling, offsetting, and linearization. To save on computing power within the microprocessor it may be expedient to carry out a certain amount of data manipulation, such as differentiation, multiplication, ratios, square roots, and logarithms. The scaling and offsetting of the signals makes the choice of an analog-to-digital converter easier.

Over the last five years, amplifier technology has provided a large number of high-performance devices, such as programmable amplifiers, FET input operational amplifiers, and instrumentation amplifiers.

There are various types of signals that require special treatment, and there is usually a particular type of amplifier that would suit that application, a few of which are discussed below.

FET input operational amplifiers are ideal devices to use when low bias currents and high input impedances are required. The high input impedances mean that higher resistor values can be used, thus minimizing input loading and current offset errors, so that improved accuracy is achieved.

Chopper stabilized amplifiers are used when it is essential to maintain low-voltage offsets and bias currents, with time and temperature variations. This reduces the need for costly calibration exercises. Currently, drifts of 0.1 μV/°C and long-term stability of 2 μV per month are achieved. The disadvantage of this type of amplifier is the possible injection of noise from the modulator.

Instrumentation amplifiers are committed gain amplifiers with an internal high-precision feedback network. They have excellent drift, linearity, and noise rejection characteristics, which makes them a good choice for extracting and amplifying low-level signals in the presence of high common mode noise voltages. These types of amplifiers are mainly used as transducer amplifiers for strain gages, thermocouples, and quartz pressure transducers.

Ratiometric Dc

The ratio conversion can be carried out using either a digital or an analog technique. The digital technique reduces the hardware requirements but loads the programming, which may be unacceptable.

For the digital approach, the signals from each leg of the ratiometer element are buffered and converted to a single-ended output. These are then multiplexed and buffered, and each signal is then digitized and converted to a single word by the processor. The processor then carries out the ratiometeric algorithm.

In the analog scheme shown in Figure 4-3, the single-ended signals are multiplexed to an analog multiplier circuit, and the output of this is then digitized. Another cost-effective method utilizes the reference input of the analog-to-digital converter. This scheme is useful as it reduces the normal mode gain errors.

Tachometers

Tachometer signals are normally three-phase and vary in frequency and amplitude when driven. These signals can be either converted to a dc voltage, which is then digitized, or directly converted into a digital format. The period or frequency can be measured; the advantage of measuring the period is that the time taken is short. As this parameter is only sampled once a second, measuring the frequency is a simpler solution.

In all cases, the three-phase signal is fed to a saturating transformer, as shown in Figure 4-4. The output is then full wave rectified. The three waveforms are then current summed using an operational amplifier. The pulses at each transition are used to increment a counter, which is reset every second. The digital output from the counter after every second bears a proportional relationship to the speed of the device being measured.

For period measurements, the output frequency from the transformer is used to gate a much higher clock frequency. This frequency is fed to a counter whose output is related to the speed of the unit being measured. The frequency output

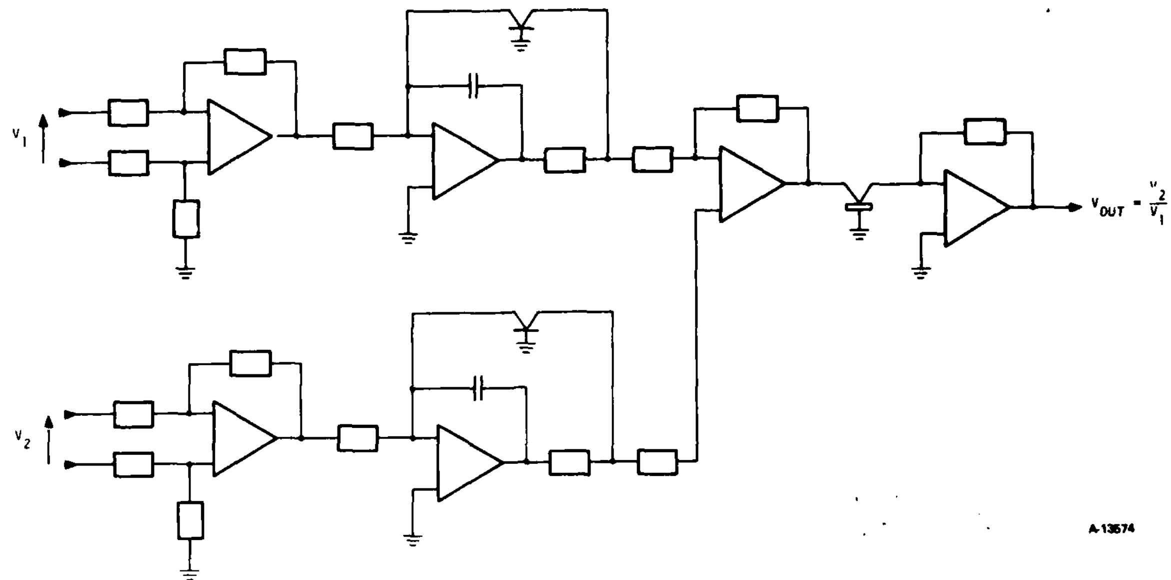


Figure 4-3. Ratiometeric Conversion

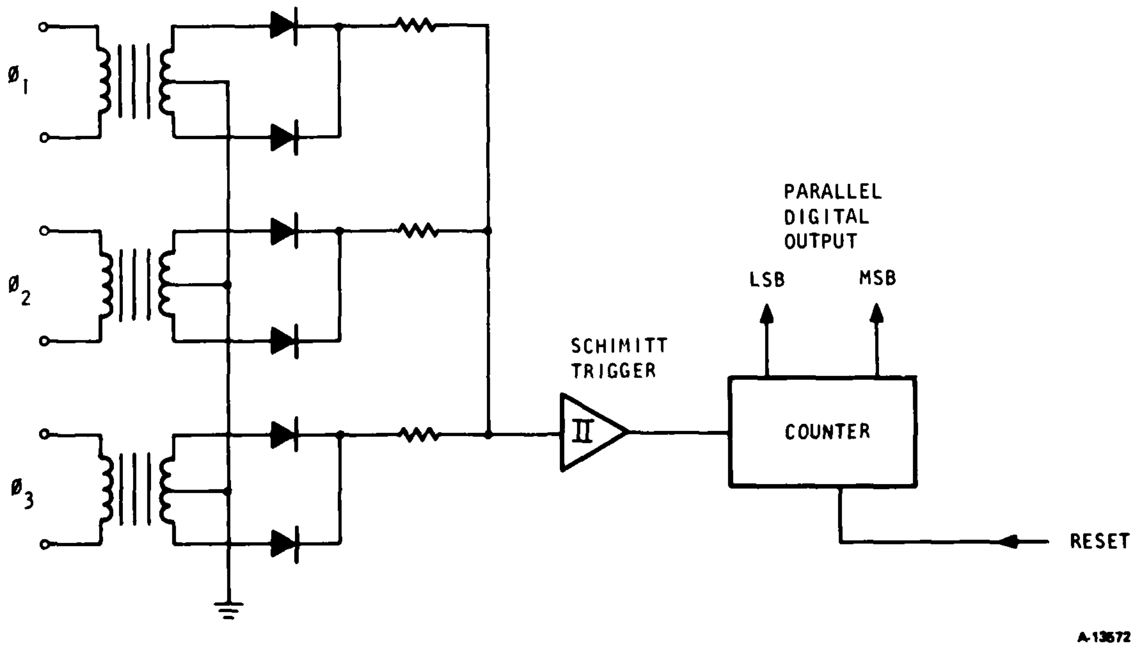


Figure 4-4. Tachometer Conversion

can be converted to a dc voltage using a diode pump circuit or a frequency-to-voltage converter. The dc voltage is then digitized using an analog-to-digital converter. This method requires a double conversion and is less accurate.

Discretes

The discretes can be in various formats such as 28 v, 5 v, open circuit, closed circuit, shunt (diode isolated), and ac. They must be converted from their formats to a definite digital signal, which has to be referenced to the logic return of the power supply within the unit. Each discrete signal would be buffered using a form of comparator. The circuitry around this device would depend on the type of discrete signal being monitored.

Analog-to-Digital Conversion

There are a number of ways of converting dc signals to a digital format. There are advantages and disadvantages to each method depending on what application it will be used for. The different methods can be divided into two groups, depending on whether they are capacitor charging or the discrete voltage comparison type.

The capacitor charging analog-to-digital converter basically depends on digital coding of the time taken to charge a capacitor to some form of reference voltage or the analog input voltage.

The discrete voltage comparison analog-to-digital converters produce a discrete voltage that is equivalent to a digital word, the discrete voltage is then compared with the analog input voltage. This discrete voltage is then increased or decreased until it compares with the input voltage. The generation of the discrete voltage can be simultaneous or sequential.

The four most common types of analog-to-digital converters are explained in the following. They are the dual-slope analog-to-digital converter, which is a capacitor charging type, and the ramp, successive approximation, and parallel analog-to-digital converters.

The dual-slope analog-to-digital converter converts the analog input voltage to a proportional time interval, which is measured digitally. This is accomplished by integrating the input for a predetermined time. The reference voltage is then switched to the integrator, and is integrated down from the level produced by the integrated input until a zero level is reached. The time taken for the second integration is proportional to the average of the input voltage during the predetermined integrating period. The time interval is then converted to a digital word using a counter (see Figure 4-5).

The dual-slope converter has a low conversion rate but has the advantage of high accuracy due to a high noise immunity and a virtually zero temperature coefficient. The main source of error is due to thermal drift within the reference voltage source.

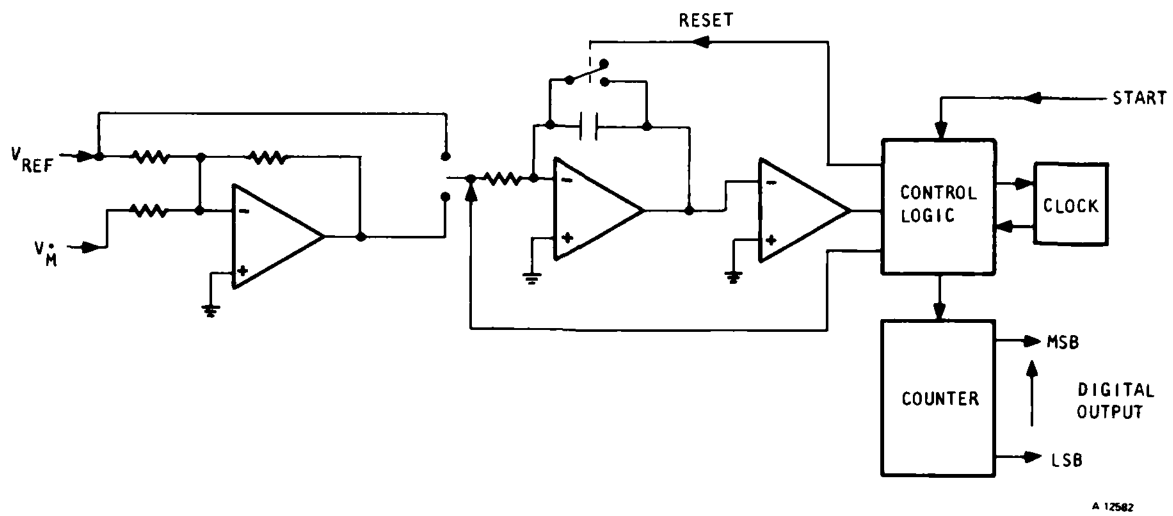


Figure 4-5. Dual-Slope Analog-to-Digital Converter

The single ramp analog-to-digital converter is the simplest of the three types but it tends to be relatively slow. The number of conversion steps required for full-scale conversion is (2^n - 1) where n is the number of bits in the digital word. The block diagram of this converter is shown in Figure 4-6. Conversion starts by resetting the counter to zero; this changes the digital-to-analog output to zero. The counter then begins counting the clock pulses, the output from the digital-to-analog converter ramps up until it is equal to the input voltage. The comparator then switches, thus closing the gate. At this time, the digital word in the counter is the digital equivalent of the analog voltage.

For high-speed conversion the required counting frequency becomes prohibitive; i.e., for a conversion time of 25 μs and a resolution of 12 bits, a frequency of 163 MHz is required.

A successive approximation analog-to-digital converter is shown in Figure 4-7. It operates by comparing the input voltage with a series of voltages generated by the digital-to-analog converter until the two are equal to within one least significant bit (LSB). The series of voltages is generated by setting each input bit to the digital-to-analog converter in turn starting with the MSB. After each bit is set the output of the digital-to-analog converter is compared with the input voltage; if it is larger the bit is reset, if smaller it is left set. This process continues until the least significant bit has been tried. The digital word at the input of the digital-to-analog converter is then the digital equivalent of the analog input voltage.

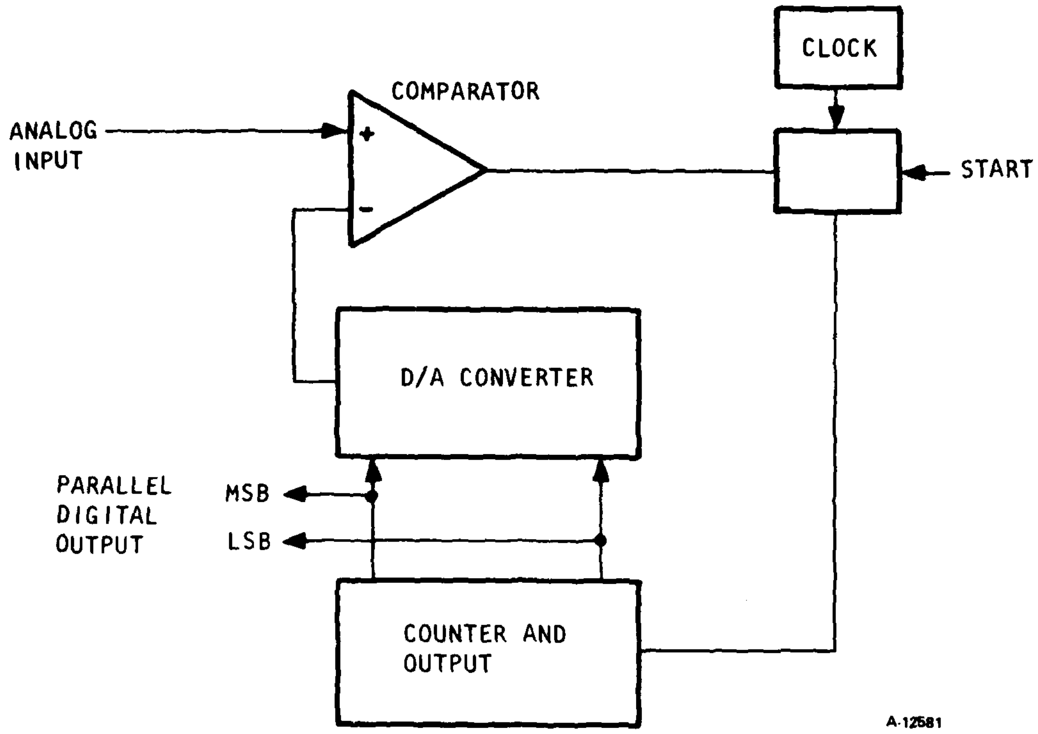


Figure 4-6. Single Ramp Analog-to-Digital Conversion

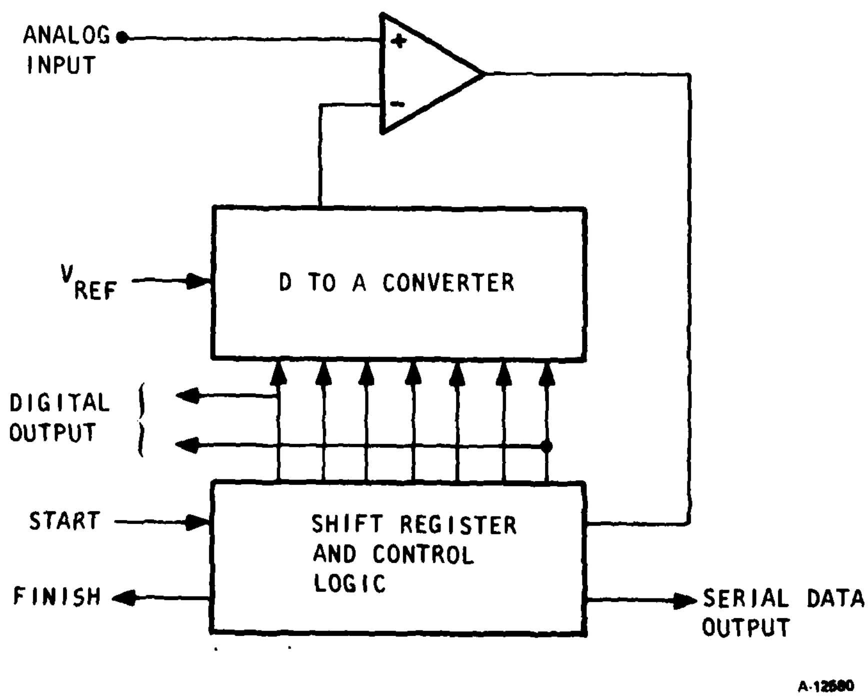


Figure 4-7. Successive Approximation Analog-to-Digital Converter

This method only requires n clock cycles to complete the conversion, where n is the number of digital bits required, hence a high conversion speed is possible. The improved speed characteristics are paid for by an increase in circuit complexity; but with present large-scale integration technology this presents no particular problem. There are a number of industry standard devices available in this configuration, thus multisourcing is possible.

The last method to be considered here is called parallel or simultaneous conversion and a circuit is shown in Figure 4-8. An analog comparator with a fixed voltage reference is used for every quantization level that is required. The outputs from the comparators then drive logic circuitry, which produces a digital word; this word is equivalent to the analog input.

A very high-speed conversion rate is possible with this circuit. The speed limits are governed by the propagation delays of the components used. The drawback with this system is the amount of hardware required to do the data conversion, it approximately doubles for each extra bit required.

A summary of the above methods is shown in Table 4-1.

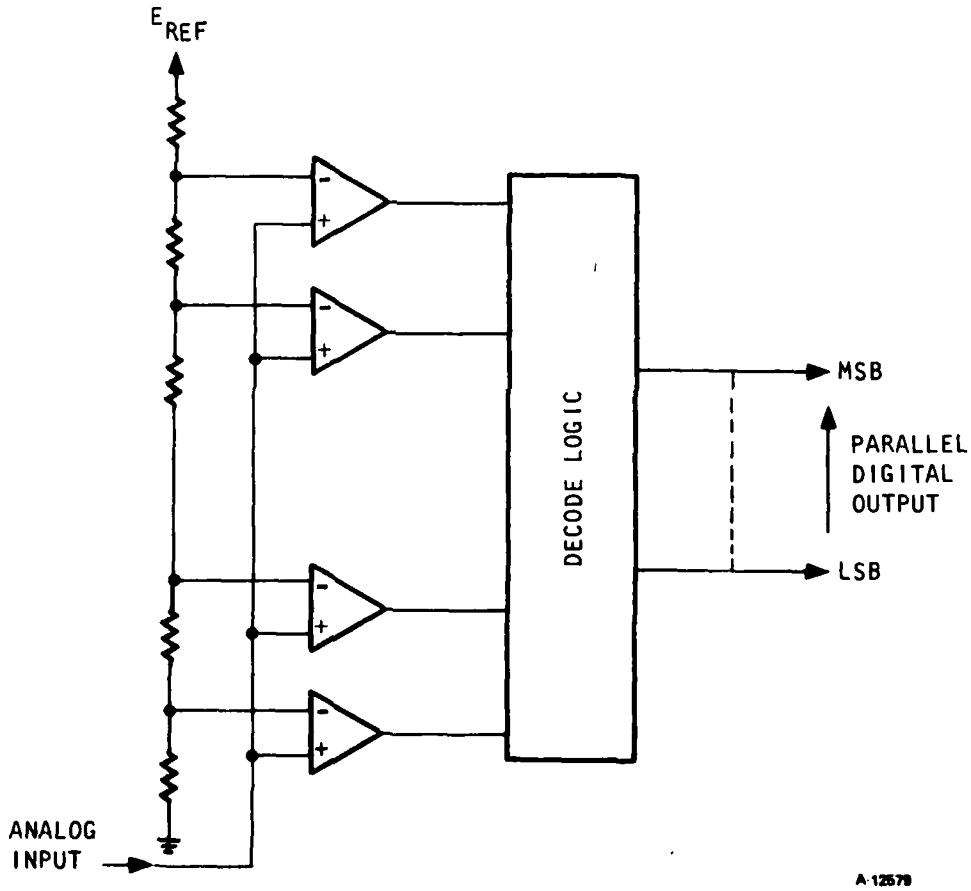


Figure 4-8. Parallel Analog-to-Digital Converter

TABLE 4-1

SUMMARY OF ANALOG-TO-DIGITAL CONVERTER

Method	Speed	Accuracy	Complexity
Dual slope	Slow	Very good	High
Single slope	Slow	Poor	Medium
Successive approximation	Fast	Good	Medium
Parallel	Very fast	Good	Very high

MULTIPLEXING

Multiplexing devices can be divided into two basic groups--electromechanical and semiconductor elements. Examples of electromechanical multiplexers are relays, crossbar switches, and motor driven commutators. They have good isolation characteristics but have the disadvantages of being bulky and expensive and requiring a fairly large amount of power; they will not be considered for this application.

The semiconductor multiplexing circuits can be divided into analog and digital functional groups. Both types use proven technologies, and devices are available from a number of semiconductor manufacturers. Digital multiplexers will be used in the system to transfer the digital data, such as the discrete signals, onto the microprocessor data bus. The analog multiplexers are fabricated using CMOS technology and can be obtained with or without input protection, each having its own use.

The protected input devices are used when interfacing directly to external equipment. This is because these units can be subject to a number of potentially destructive conditions:

(a) Signals may be present when power has been removed from the multiplexer.

(b) Induced voltage spikes from nearby sources.

(c) Static discharge during fitting and maintenance.

(d) Grounding problems.

(e) Accidental shorting to incorrect signal sources.

A common failure mode with this type of device is latch up. This can be avoided by selecting devices that employ such technologies as floating body and buried layer. These devices greatly reduce the effects of overvoltage latch up. Protected devices also have the disadvantage of having a higher on resistance due to the added series current limit resistance.

Unprotected multiplexers are ideal for use within the system where there is no danger of damage from transient voltages; for example, between the analog-to-digital converter and the signal conditioning circuits. They also have better performance characteristics because they are free from the compromises used to solve the latch up problems.

Besides the different devices available for multiplexing there are different techniques that can be used, such as voltage, current, and flying capacitor multiplexing. Each technique has its own advantages and disadvantages.

The flying capacitor multiplexer is used for low-level signals. It provides considerable immunity from common-mode interference and is essentially a floating two-wire sample hold. The common mode interference is not transferred across the switches.

Voltage multiplexing can be used for either high- or low-level signal multiplexing. When used for low-level multiplexing (i.e., less than 1 v), a differential multiplexer should be used to obtain the required accuracies. Problems that most frequently arise with low-level signals are due to thermal effects and interference. The lines are run in pairs, and differential techniques are used to remove any interference that is introduced as a common mode signal. Care must also be taken when multiplexing differential signals to ensure that the matching between the switches is good, otherwise the common mode rejection is reduced.

The most common type of voltage multiplexing for a high-level signal consists of a bank of switches connected to a common output bus, as shown in Figure 4-9. The output bus is then buffered using a noninverting operational amplifier. This configuration has the advantage of being simple and offers a high input impedance. The range of input signal voltage depends on the choice of multiplexing switch and is governed by the breakdown voltage of the CMOS gate.

Current multiplexing is used for switching of high-voltage inputs. A typical configuration is shown in Figure 4-10. The switching takes place at the summing junction with protection diodes to ground; hence, the switches are never exposed to high voltages. This type of multiplexing has high immunity to transient voltages and a constant input impedance while conducting, and is safe when the power is removed from the multiplexer. With modern technology devices the input impedance can be high, thus swamping out the source and multiplexer on resistance and giving a high degree of signal isolation. The gain of each channel is easily adjusted by adding the appropriate resistor value to the input (Rc).

This circuit can be further improved by exchanging the clamping diodes with a complementary switch. This ensures that the input resistor is always terminated to a virtual ground, thus the input impedance is constant. This avoids settling problems at the transducer due to load changes. Current multiplexing also reduces the affect of line and interconnection resistances.

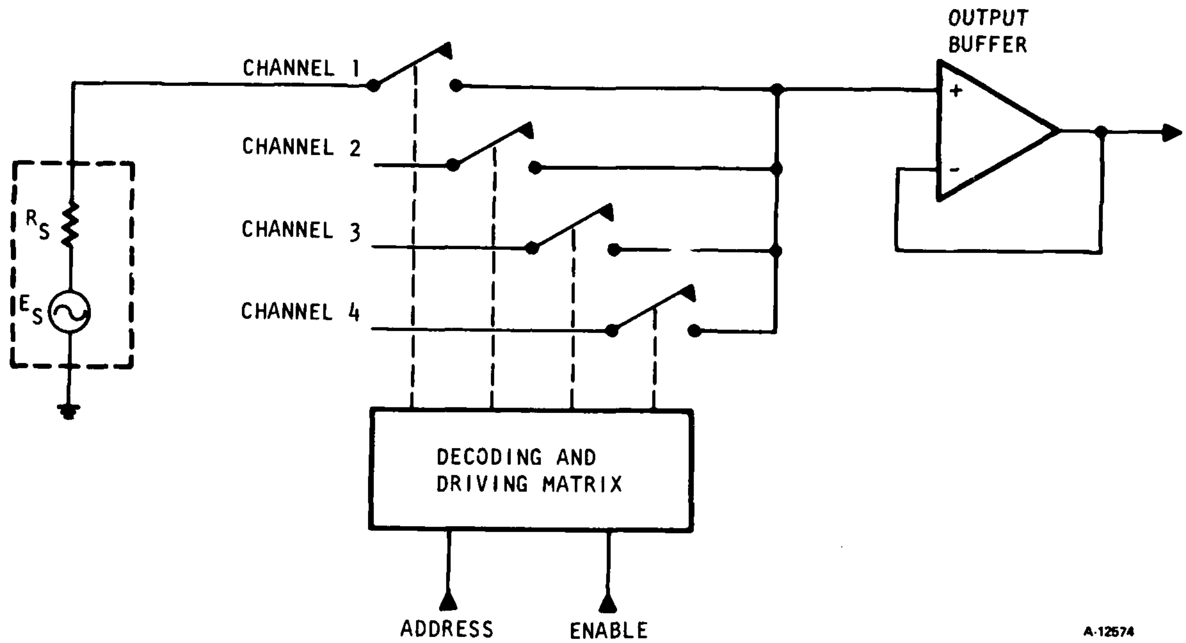


Figure 4-9. High-Level Voltage Multiplexer

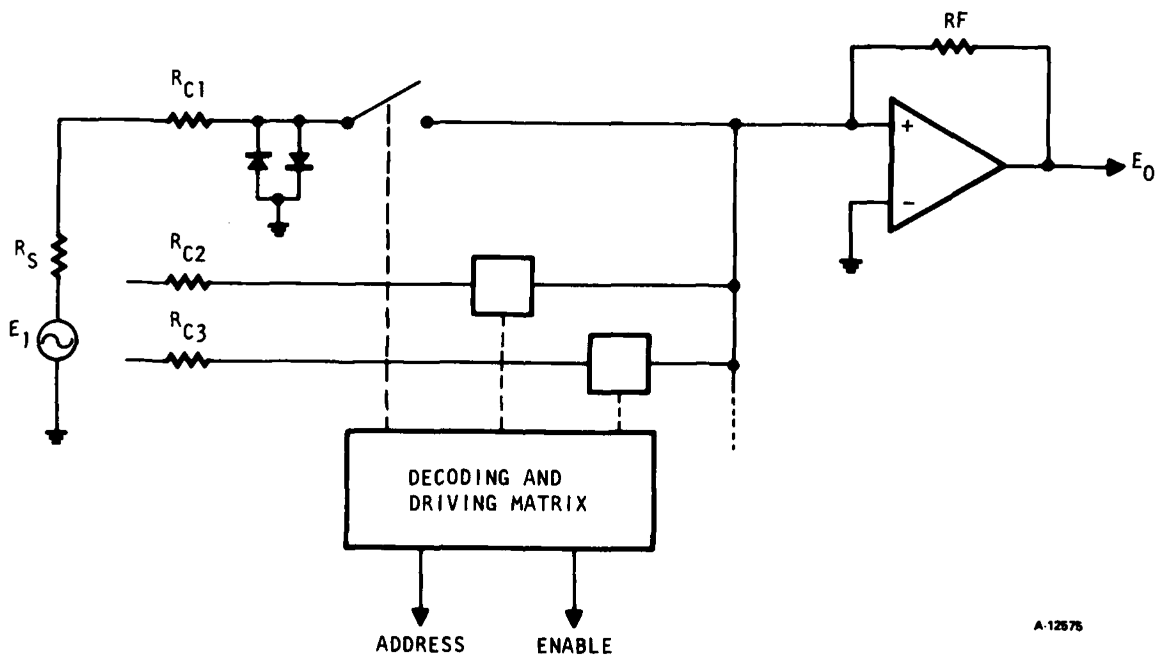


Figure 4-10. Current Multiplexing

Both types of multiplexers suffer from the static and dynamic types of error. Static errors originate from switch leakage, offsets in buffer amplifiers, and gain errors due to on resistance, source resistance, amplifier input resistance, and gain nonlinearity. Dynamic errors are due to charge injection from the switch control voltages, settling times on the common bus, crosstalk, and amplifier settling characteristics. The dynamic errors can be greatly reduced by careful design and layout of the circuit.

If current multiplexing is used, consideration must be given to the leakage currents in the switches, which are temperature dependent. The leakage current generally doubles for every 10°C rise. This means that the number of channels that are multiplexed onto one bus is limited, otherwise large input offsets are created if the following circuit has a high input impedance.

<u>1553 Interface</u>

Two chip sets are available for the design of a remote terminal unit. These are manufactured by Harris Semiconductor and Smith Industries Ltd.

The Smith chip set is made up from two large-scale-integration chips, each with its own specific function. Device one is a data validation Manchester code/decode function, one of these is required for each bus to be monitored, hence two are required for a dual bus. Device two is a protocol sequencer and only one is required per remote terminal unit. To make up a complete remote terminal unit using these devices extra components are required, such as coupling transformers and clock circuits. Both of the chips require only a 5-v supply.

The large-scale integration process enables a very compact remote terminal unit (RTU). The only disadvantage with the Smith chip set is that it can only be used on the 1553B standard data bus. Normalair-Garrett Limited (NGL) is currently evaluating this chip set, using one of the Smith early production units.

The Harris device is fabricated using CMOS technology and is designed as a Manchester encoder-decoder. It requires a large amount of support hardware to interface to the system microprocessor data bus and the protocol sequencing of the 1553 data. This makes the complete remote terminal unit more adaptable to various standards of the 1553 system. The board area required for this system is approximately double the amount of the Smith Industries system.

DATA PROCESSING DEVICES

The crash survivable flight data recorder (CSFDR) system must be managed by some type of digital control. This can be accomplished by either a discrete logic control circuit or a microprocessor. The optimum solution is to use a microprocessor. The tasks that the microprocessor must accomplish are data compression, multiplexing control, analog-to-digital conversion manipulation, data compilation, and built-in test routines.

There are on the market a variety of microprocessors; both 8- and 16-bit devices are currently available. Based on the amount of work that is required for configurations I and III, a 16-bit microprocessor has been chosen, while an 8-bit microprocessor would probably suffice in the case of configuration II.

In the 16-bit microprocessor range there is currently a choice of four. The Texas Instruments TMS9900 has been used in military projects for a number of years. A derivative of this (PB59900) is being produced, and employs I^2L technology. Availability in a military version is uncertain, and second sources are questionable; in addition, some special interface circuits are required.

Motorola has under development a 16-bit microprocessor (68000). This device shows a lot of promise; but it is unlikely to be available in a military version before 1984.

The Intel 8086 is presently being incorporated in several airborne system designs at AiResearch. This unit has some performance limitations, but the unit has a demonstrated capability in the airborne environment.

The most promising 16-bit microprocessor that is presently available is the Z8000. It has the advantage of being manufactured by two companies--Zilog and Advanced Micro Devices. Zilog has the Z8000 available to conform to MIL-STD-883 and expect approval of the MIL-M-38510 in the second quarter of this year. It is expected that Advanced Micro Devices will follow closely behind Zilog with their military version. NGL is currently evaluating this processor for avionic equipment as the United Kingdom Ministry of Defense shows signs of standardizing this device. The U.S. Air Force is also supporting development of HOL compiler capability for this device, and it may become a U.S. military standard also.

There are a number of 8-bit microprocessors available to military specifications that are all well proven. The primary choice is between the Intel 8080, Motorola 6800, and the Zilog Z80. All three devices have been used by AiResearch and NGL. The 6800 is the only device that is currently available to full qualification under MIL-M-38510. The others are available under the MIL-STD-883 screening process.

DATA COMPRESSION ALGORITHMS

To record at least 30 min prior to an accident, the configuration I data rate would require approximately 3 Mbits of uncompressed data to be stored in the crash protected memory. This figure does not include any storage that might be set aside for additional data such as takeoff or incident information. In view of the relatively high incremental cost, size, and power requirements of solid-state memory as compared with magnetic tape, together with the desire to evaluate the potential of a solid-state store, considerable effort has been put into studying ways in which the storage requirements might be reduced by application of data compression techniques.

Delta coding (i.e., storing differences in signal amplitude) and zero order prediction (e.g., floating limit threshold) are common techniques for achieving point-of-source compression, mainly because of their ease of implementation and relatively high efficiency. With the advent of more powerful microprocessors and the experience from a wide variety of fields becoming available where compression is now successfully being applied (see Table 4-2) it is appropriate to reappraise the possible algorithms that might be successfully applied to CSFDR systems for onboard data reduction.

TABLE 4-2

APPLICATION AREAS OF DATA COMPRESSION

Data Source	Examples of Data Compression Advantages
Seismic data from geophones	Rugged and transportable on-site data acquisition system
High energy physics data from particle detectors	Reduction of data storage requirements, especially in rare event experiments
Telemetry and communication data from satellites	Reduction of transmitter power and ground storage requirements
Electrocardiogram data	Real-time transmission over telephone lines and reduction in hospital storage requirements and file retrieval time
Electronic mail	Increased traffic capacity

Two forms of data compression should be identified--reversible compression, where complete data recovery of the original information is possible through the appropriate decompression algorithms, and irreversible compression, which does not permit the recovery of the original information without some loss or distortion.

For a compression technique to be information preserving implies that there must have been redundancy in the original data. Such redundancy may be obvious as in the case of a 12-bit analog-to-digital value being stored in two bytes. Other forms of redundancy arise from the fact that certain values or sets of values occur more often than others. In such cases compression may be achieved by designing codes which allow one to assign the most compact codes to the values with the highest probabilities of occurrence. However, the main difficulty with applying these encoding schemes to the CSFDR system is that under critical flight conditions the probabilities used for constructing the code book could be considerably different from those observed under cruise conditions. Hence, data expansion rather than data compression may occur. Methods have been suggested for overcoming the difficulties experienced by changing source probabilities by use of adaptive algorithms (e.g., Ref. 4-1). However, these techniques rely on accumulating large data samples, or training sets, and hence tend to react rather slowly to signal statistic changes as well as providing poor data security. Also, for signals with a large dynamic range, the code books and corresponding search time tend to become large. However, coding algorithms that grow only linearly with block length are being developed so that real-time compression still remains feasible.

Two approaches may be adopted to the information distortion introduced by the irreversible techniques (i.e., signal approximation). Either the allowable distortion may be limited and the data rate minimized or the maximum rate fixed and the distortion minimized. For the CSFDR system the second approach is the most suitable, in order to ensure that an adequate period of pre-accident information is recorded.

Predictors and interpolators allow data points that lie within a certain tolerance or aperture not to be stored. These algorithms are in general simple to implement and there is a direct relationship between the tolerance and the resultant mean square error of the reconstructed data. However, the higher order methods are particularly sensitive to noise.

Polynomial approximations such as spline fits are a useful way of parameterizing the data and of smoothing out noise. However, because they require more computing power and precision, and because they operate on a set of samples accumulated over a large period of time, the chance of data staleness is increased.

Transformations such as the Karhuren-Loeve attempt to discover redundancy in the data by searching for components that do not add significant information. Such a transformation is successful if there is an underlying approximate linear relationship in the data. Similarly, a Fourier transform will achieve compression of data that is essentially sinusoidal in nature by allowing it to be represented by relatively few frequency component coefficients.

Clearly, all these techniques depend on the nature of the signals, and again the problem of the signal form changing significantly under certain critical flight conditions may lead to data expansion. However, this very problem suggests their usefulness in a discriminatory role, either for flagging recording requirements in abnormal flight conditions, or as a more sophisticated measure for maintenance data recording decisions than simple thresholding on single parameters.

The choice of data organization within the crash protected memory will be critical in determining the final compression figure achieved. In a basic fixed frame format all the data to be recorded is stored, and hence the positional information identifies each variable and only the elapsed time need be recorded for each base time period (frame). At the other extreme a fully variable format allows any selected variable to be stored and identified by tagging the value with a parameter identification and a time. However, such a format can introduce considerable overheads, expecially if there is a large parameter set and high sampling rates, due to the long variable identification fields.

In practice, the optimum choice of format depends both on the frequency of the data coming from the compression algorithms and the degree of data security and integrity required. All these ideas will be reviewed in more detail in the following sections in order to provide the basis for the optimal choice of compression algorithm and store layout design.

<u>Predictors and Interpolators</u>

Among the simplest algorithms to implement are the low-order predictors and interpolators. In prediction, a new sample value is effectively decomposed into a part that is correlated with past samples (e.g., a linearly weighted sum) and a part that is uncorrelated with them (i.e., the prediction error). Interpolators are implemented in an analogous way to predictors except that the estimator consists of a combination of past and future samples.

The most commonly used predictor is the zero-order with floating limits in which a tolerance band is placed about the last stored value. If the following sample lies within this aperture it is not stored. Otherwise, it is stored, and a new aperture is set up around this new sample value (see Figure 4-11a). In common with other compression routines, a time-tag or run length indicator needs to be associated with each stored value. One strategy is to associate a bit with each sample, those not successfully predicted having the corresponding bit set to zero, and those successfully predicted having the corresponding bit set to one (Figure 4-11b). Another strategy is to store a time code along with each value (Figure 4-11c). For the run-length method (Figure 4-11d) the number of times a value has been used to predict successive samples is stored.

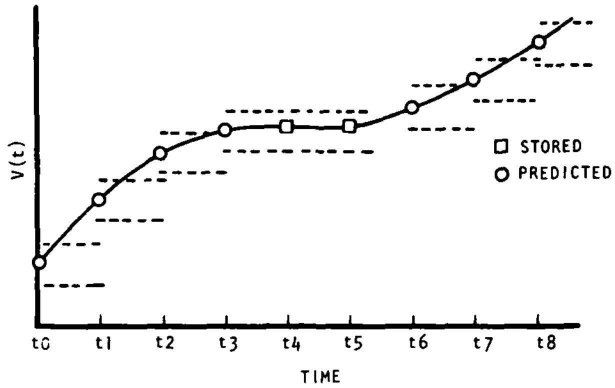
Figure 4-12 illustrates the performance of a zero-order predictor with floating limit on data published in Ref. 4-2. It can be seen that even though the signal is fluctuating rapidly data compression is possible. With zero tolerance the algorithm is completely reversible. If the tolerance is increased to ± 1 digitization (LSB = 0.01 g), the algorithm is no longer truly reversible although the effect on the recorded data is primarily that of filtering out noise. Larger tolerances clearly reduce the fidelity of the reconstructed signal although many of the important characteristics remain. The corresponding compression and mean square error for different tolerances is shown in Figure 4-13a along with those for the first 30 sec of data (medium activity) and final 30 sec of data (high activity).

Results are shown in Figures 4-13b and 4-14 for a first-order predictor using the past two samples as a straight line prediction to the same data. It can be seen that the higher-order predictor performs no better than the zero-order predictor on this particular data. Experience from other fields (Refs. 4-3, 4-4) confirms that in general, as the order of the estimator increases, the compression ratio decreases along with the mean square error.

The results of Figures 4-13c and 4-15 demonstrate the higher compression rates achievable during the same periods on a different parameter (LSB = 0.35 deg).

The main problem with interpolation is one of data staleness, especially in the situation where there are a large number of interpolated points lying between the current data sample and the previous stored value. The problem could be overcome by some method of intermediate nonvolatile memory storage but the usual problems of processing time and store location read-write lifetime make the solution nontrivial.

It therefore appears that the zero- and first-order predictors represent the best compromise between complexity, compression ratio, and signal preservation. The first-order predictor offers advantages over the zero-order prediction only over periods where the signals are changing at a relatively



(a) ZERO ORDER PREDICTOR WITH FLOATING LIMIT

0 0 0 0 1 1 0 0
V(t0)
V(t1)
V(t2)
V(t3)
V(t6)
V(t7)
0 1 1 1 1 0 0 1

(b) HEADER CODE FORMAT: 1 = VALID PREDICTION

START OF FRAME t0-t7	
000	V(t0)
001	V(t1)
010	V(t2)
011	V(t3)
110	V(t6)
111	V(t7)
START OF FRAME t8-t15	
000	V(t8)

(c) TIME CODE FORMAT: MISSING TIME CODE MEANS PREDICTION IS SUCCESSFUL

START OF FRAME t0-t7	
00	V(t0)
00	V(t1)
00	V(t2)
10	V(t5)
00	V(t6)
00	V(t7)
START OF FRAME t8-t15	
00	V(t0)

(d) RUN-LENGTH METHOD CODES NUMBER OF SUCCESSFUL PREDICTIONS

A-12584

Figure 4-11. Operation of Zero-Order Predictor on Typical Input Data

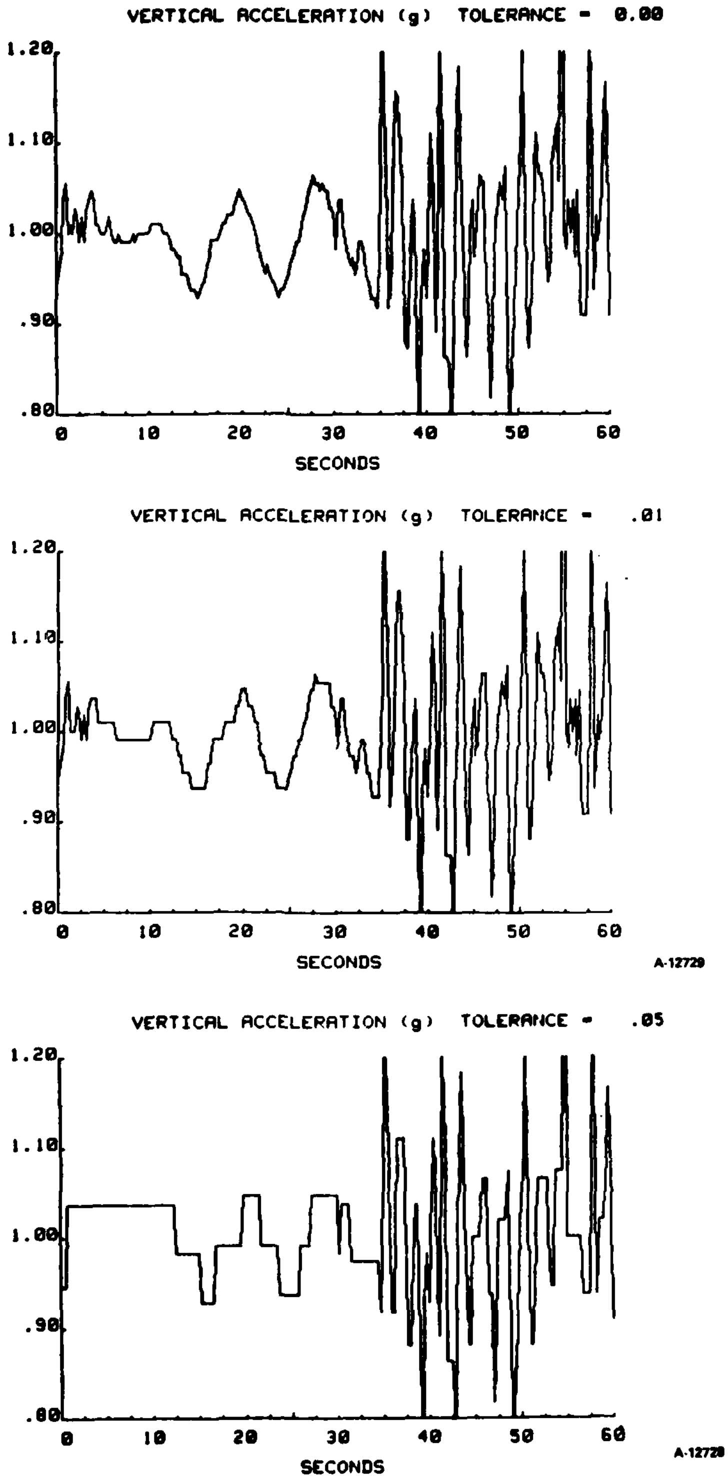


Figure 4-12. Predictor Performance with Variable Tolerances

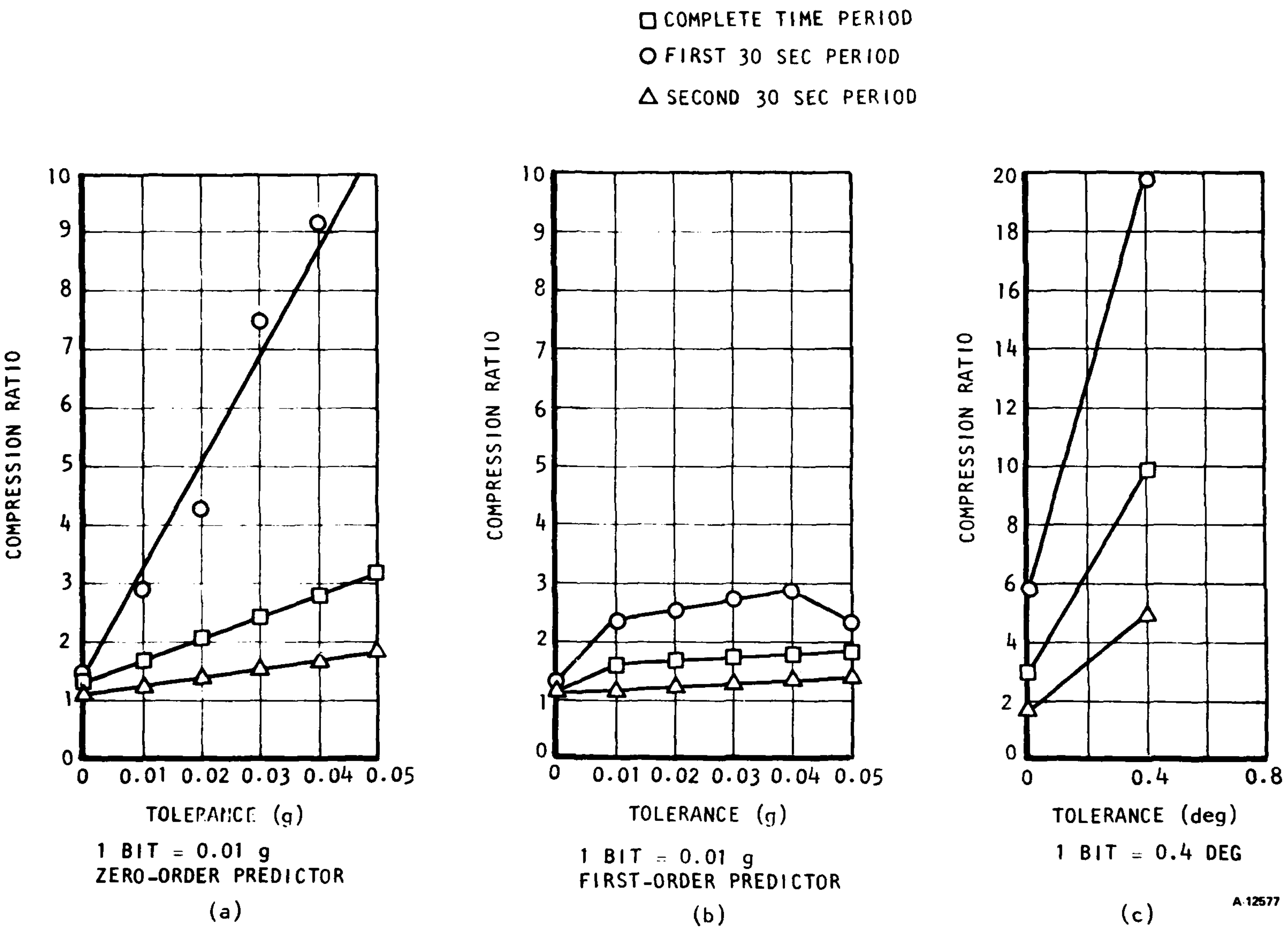


Figure 4-13. Tolerance vs Compression Ratio

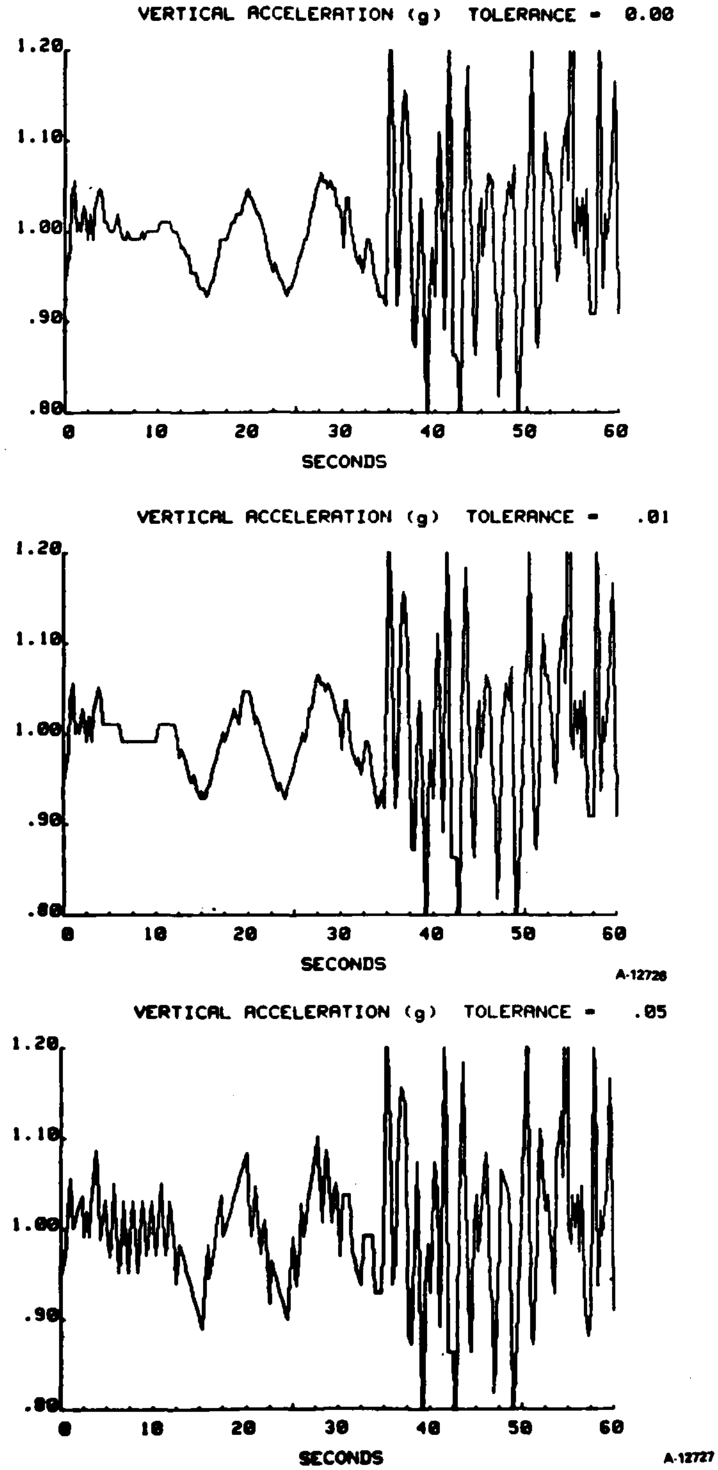


Figure 4-14. First-Order Predictor Performance with Variable Tolerance

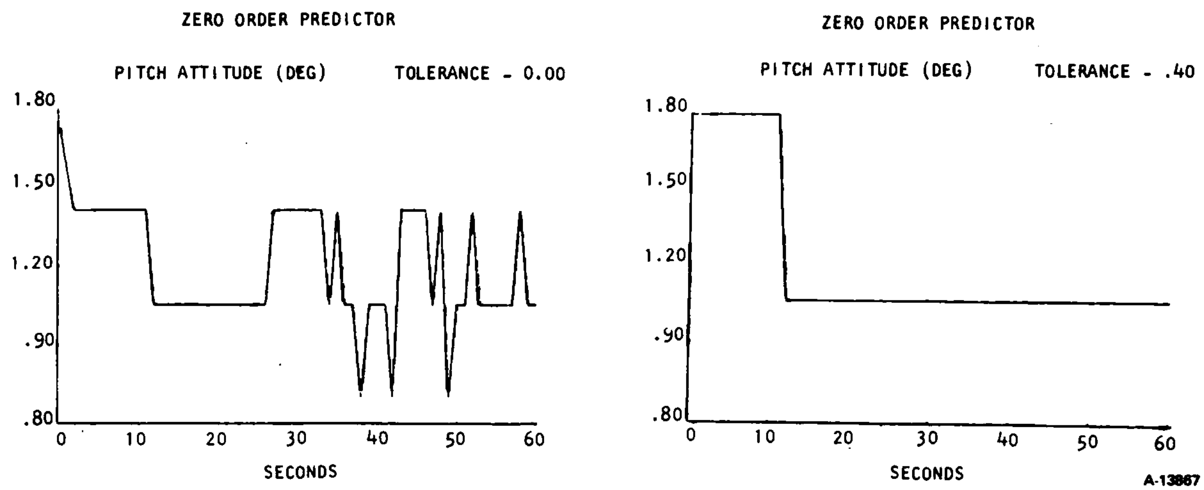


Figure 4-15. Effect of Tolerance on Zero-order Predictor for Pitch Attitude

constant rate. The higher-order predictors become very noise sensitive (e.g., Ref. 4-3), as can be seen from the larger tolerance values of the first-order predictor.

Adaptive Compression

In principle, a predicted sample may be estimated by using a linear weighting of N previous samples:

$$X_p(t_n) = \sum_{j=1}^{N} B_j \; X \; t_{n-j}$$

where for the first-order predictor described above N=2, B_1=2, and B_2=-1 (i.e., a simple straight line prediction passing through point X (tn-2) and X (tn-1). However, the coefficients Bj can be calculated so as to produce the best signal fidelity. In practice, two difficulties have been found with this approach:

(a) The signal characteristics can vary quite considerably with time so the optimal set of coefficients is continually changing. This would cause overheads in storing the coefficients to allow signal reconstruction as well as a slow response time due to the learning period required to estimate the optimal Bj from the signal.

(b) The optimal Bj can only be calculated in some mathematical sense (e.g., mean square error) but such measures are notoriously poor as criteria for obtaining the best signal fidelity. A good example of this is in electrocardiogram data where certain important morphological features can be lost using algorithms that appear to give a better mean square error than those that retain the important diagnostic characteristics.

Entropy Encoding

There is an obvious redundancy within each signal in that neighboring samples are not independent. Thus, each sample could be more economically represented by a difference from a previous value rather than an absolute value. Such delta values would require storage of the absolute value at regular intervals in order to allow reconstruction of the original signal and to ensure data integrity.

Even if the delta values are stored, redundancy still remains in that the values do not occur with equal probability. Figure 4-16 illustrates this probability of occurrence for the data of Figure 4-12 for differences that can be contained in 3 bits (8 levels, Figure 4-16a) and five bits (32 levels, Figure 4-16b).

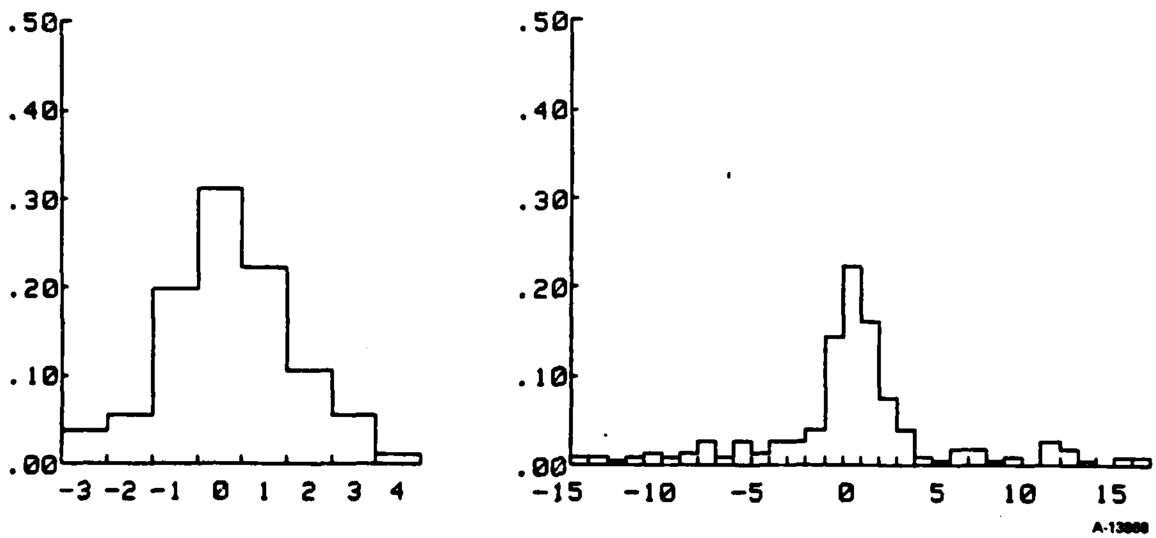


Figure 4-16. Probability of Occurrence for Different Deltas Over Two Delta Ranges

One of the simplest ways of coding the data taking into account the statistical characteristics of the signal is through the application of an encoding technique such as that due to Huffman (Ref. 4-5). By using probabilities derived from the differences rather than absolute values, the sensitivity to input signal types can be greatly reduced. The zero-order entropy will give a measure of the maximum compression possible:

$$H = - \sum_{i=1}^{i=n} P(X_i) \log_2 P(X_i)$$

where $P(X_i)$ is the probability associated with each of the n possible difference values. From the probability distribution of the deltas it can be seen that there is a strong underlying statistical dependence of the deltas even on data that is rapidly varying. The zero entropy calculation on this particular distribution gives a theoretical limit for compression of 1.3. A simple encoding strategy gives a compression of 1.2.

However, the penalty for this compression is a decrease in data integrity (always true if redundancy is removed) and an increase in data management complexity due to the variable length values in memory. In general, it is found (Refs. 4-1, 4-3, 4-4) that compression ratios of 1.2 to 2 are typical depending on the nature of the signal, in particular the amount of redundancy in the raw data.

There are therefore useful gains to be made by entropy encoding and a more detailed study of optimal coding strategies would seem worthwhile (e.g., Refs. 4-5, 4-6), particularly as the previous example probably represents the worst-case situation (i.e., a rapidly fluctuating signal). However, more accurate compression figures will have to be obtained using larger samples of data before it can be assessed whether entropy encoding should be included in any final design. There is a significant compression available, and the choice of a flexible data format would allow it to be included at a later stage.

Kahurnen-Loeve Transformation

Entropy encoding is not the only way in which redundancy may be removed. The Karhuren-Loeve transformation (KLT) (e.g., Ref. 4-7) is basically an orthogonal transform that is optimum in a mean-square error sense: a least squares fit in high dimensionality. The principle is shown in Figure 4-17 for a two-dimensional distribution of data points. It is clear (although this is not true if one inspects values from a higher dimensional space, e.g., a 30-dimensional space of 30 aircraft parameters) that the points lie distributed around a line. The KLT provides an orthogonal transformation that minimizes the mean square error of the data within the new coordinate set (Figure 4-19b). Further, it can be arranged that the axes are ordered in a way that reflects the relative importance of the information contributed by each dimension (Figure 4-17c). Hence, the name 'the method of principle components' is often attributed to this transform. In the above example, X1' contains more information than X2' and depending on what error can be tolerated, it may be that measurements X2' can be ignored. Hence, the original two-dimensional data could be approximated by one-dimensional data.

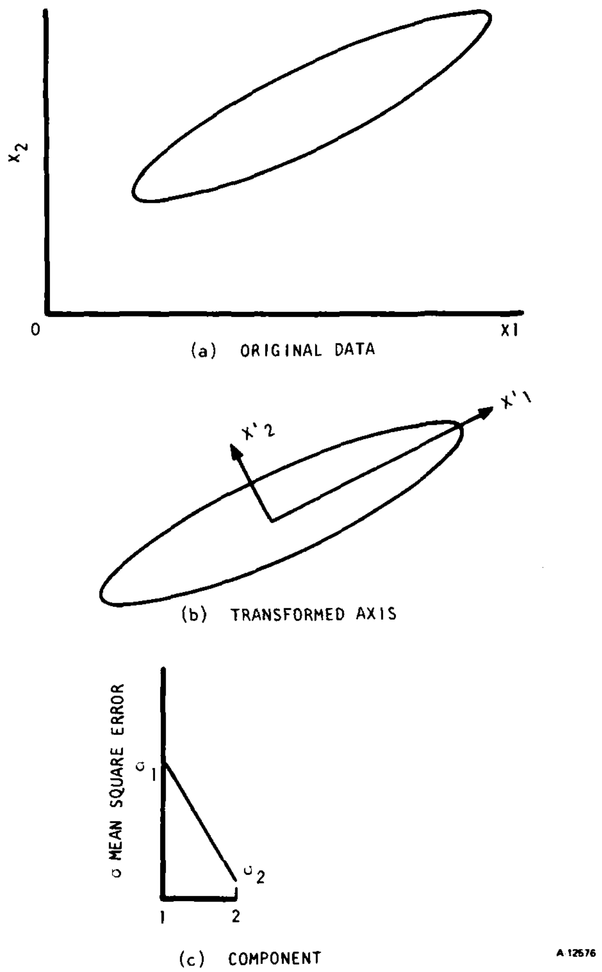


Figure 4-17. Karhuren-Loeve Transformation Example

The calculation of the values from this function is straightforward and can easily be performed onboard, especially with the advent of more powerful microprocessors.

Other transforms such as Hadamard are available, and the next phase should be used to assess the suitability of these transformations and the complexity-benefit tradeoffs performed in more detail.

Algorithm Selection

In view of the wide variety of signal types it was decided that the zero-order predictor with floating limit would probably give the best trade-off between algorithm complexity, compression ratio, and the signal-type independence. Apart from the results presented it has been shown that the algorithm achieves compression ratios of between 2 and 60 for a typical range of telemetry signals (Ref. 4-8). For flight data overall compression ratios of around 10 for cruise data and 4 for data recorded during turbulence have been recorded (Ref. 4-2) using zero-order prediction and simple data packing rules. By choosing a tolerance equal to the accuracy requirement for each parameter of zero the data compression would be truly reversible, although a slightly greater tolerance would possibly be acceptable for suppressing noise.

By storing only delta values a further compression ratio of two is easily obtainable although the full precision values would have to be stored at regular intervals in order to ensure data integrity.

However, with a 16-bit microprocessor onboard much more processing power than the above algorithm requires is available. This power could be used to implement an optimal coding strategy where possibly another 30 percent of reversible compression could be achieved. The other area where the implication of inclusion of a new generation microprocessor should be studied is onboard analysis. Such transformations as Karhuren-Loeve could offer more sophisticated measures on which to base recording strategies, whether it be for crash or maintenance data. These transformations could also be used to remove redundancy, which exists because the parameters themselves are not completely independent. For example, if the power lever angle changes, there will be a consequent change in other parameters such as the engine speed, fuel flow, etc. These techniques should be studied in more detail in the next stage since they could offer significantly better compression than has been previously possible.

Data Format

In order to estimate the final compression figure obtainable it is necessary to consider the organization of the crash protected memory. There are many formats that may be defined, each of which will be optimal under certain operational conditions and assumptions. The main considerations are:

Efficiency--Minimization of identification overheads.

Flexibility--Possibility of being able to add new information or define minor changes in store.

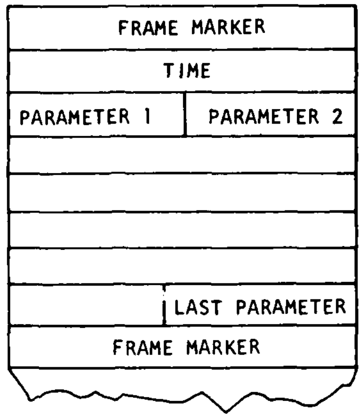
Integrity--Minimization of data loss if incorrect bits stored.

Simplicity--Minimization of processor formatting overheads.

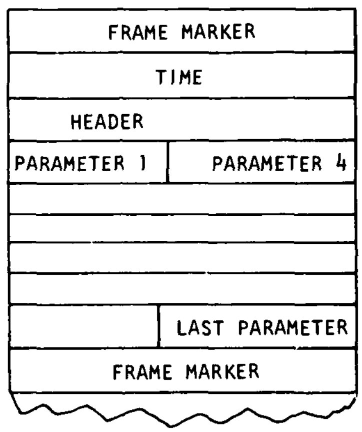
Three basic formats are described below as being representative of the types of memory organization possible. All the other organizations are basically a mixture of these formats optimized by taking advantage of knowledge of the form of the data.

Fixed Format

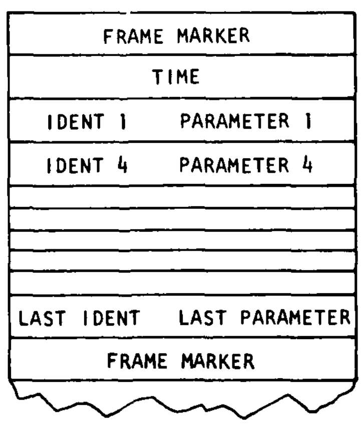
The most straightforward layout is the fixed format where all the data over a certain fixed time interval (frame) is recorded, each sample variable being identified by its relative position within that frame (Figure 4-18a).



(a) FIXED FORMAT



(b) HEADER FORMAT



(c) IDENTIFICATION FORMAT

Figure 4-18. Possible Data Storage Formats

In order to ensure the start of the frame is correctly identified, synchronization bits are usually written in the form of a header. Although this format is simple and has high integrity and low data management overheads, compression will only be achieved if no parameter within the frame requires storing.

Variable Format and Header

If a variable format is defined, each variable can no longer be directly identified by its relative position within a frame. One method of overcoming this difficulty is to associate a single bit with each value, which may be stored in the frame (Figure 4-18b). If a sample has been stored, the corresponding bit in a header word is set. If the sample is not to be stored (e.g., it was removed by the compression algorithm), the appropriate bit is set to zero. The method is inefficient for high compression rates and large variable sets due to the large overhead of storing a relatively long header. However, careful grouping of the data into groups of parameters that are correlated and use of headers and subheaders may be used to overcome this difficulty.

Variable Format and Identification

In this method a unique identification tag is associated with each value (Figure 4-18c). This is straightforward, but for a large number of variables the identification word becomes long. Again, by subdividing the parameters into groups, shorter identifications may be defined.

Figure 4-19 provides a guide to the overall compression ratio achieved by these formats assuming that only a certain percentage of 256 possible variables in a frame require storage (4-bit delta variables have been assumed). Under these conditions, the fixed frame provides no compression, the variable format with identification provides the best compression for only 10 percent or less of the variables requiring storage (i.e., a compression of better than 10:1 from the algorithms), otherwise using a header is more advantageous. The crossover point varies depending on the actual number of variables, their precision, and the way in which the data might vary, but the general trend is the same.

A tradeoff of these factors has been performed to define a format for the system configurations on which the balance of the study is based. This data format is shown in Figure 4-20. The basic 16-sec frames contain the synchronization markers, the unique time code, and the parameter origins necessary to ensure that they are self-contained units from which the compressed data may be reconstructed. Each frame consists of sixteen 1-sec subframes of delta-coded information. The subframe has a unique time code, allowing a complete subframe to be discarded should no deltas change from their values in the previous subframe. The first subframe (time code 0000), however, is always recorded since it contains the full precision origins. Within each subframe is a mixture of the identification (group) and header codes. In the same way as the subframes, if none of the deltas within a group change from their previous recorded values, the group does not have to be stored. By grouping correlated parameters together, the chance of being able to discard a complete group is maximized.

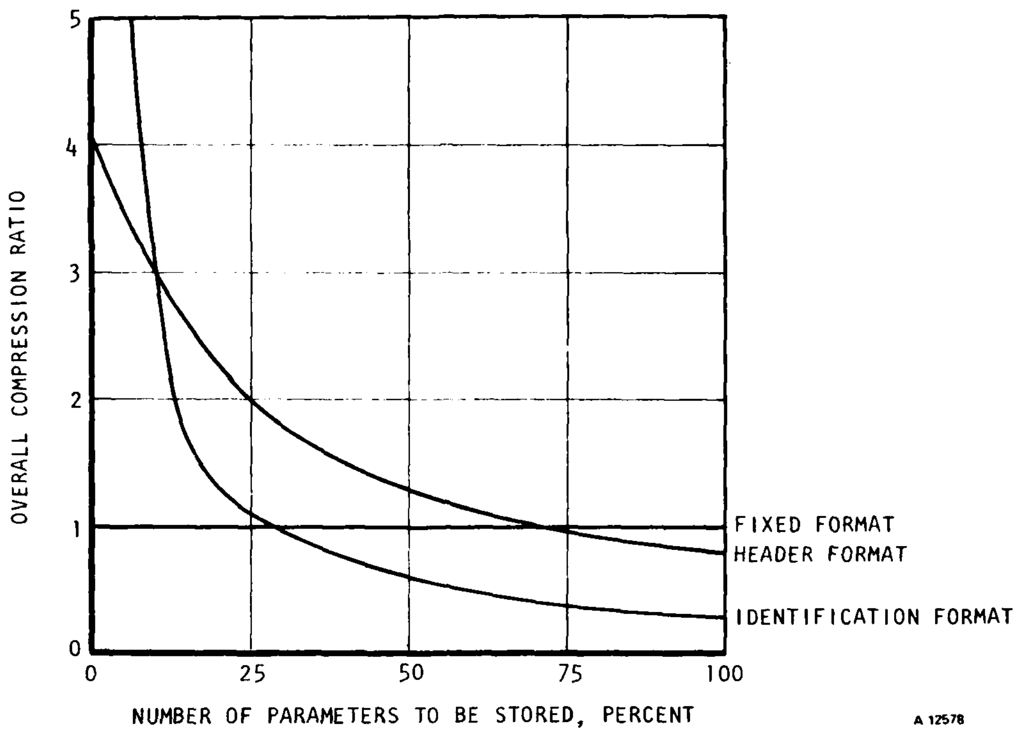


Figure 4-19. Overall Compression for Three Basic Formats

Conclusion on Store Format

The store format is a compromise between compression, security, and flexibility. However, unless great care is taken in the memory organization, any gain achieved by the compression algorithms could be lost, resulting in data expansion. The proposed format, together with the delta encoding technique, should ensure that there are no overheads introduced by the store formatting.

Audio Recording

A bandwidth of 3 kHz is considered acceptable for adequate intelligibility if the audio recording is limited to speech. If the analog signal is band-limited to 3 kHz and sampled at 6 kHz (the Nyquist rate), then a data rate of 72 Kbit/sec would be obtained from a 12-bit A/D converter.

By use of nonlinear encoding (using high resolution for the low amplitude signals and reduced resolution for high amplitude signals) an 8-bit analog-to-digital conversion could be used without significant loss of information, giving a data rate of 48 Kbit/sec.

Since neighboring values will show a significant correlation, each sample could be more economically represented by a difference between samples. Four

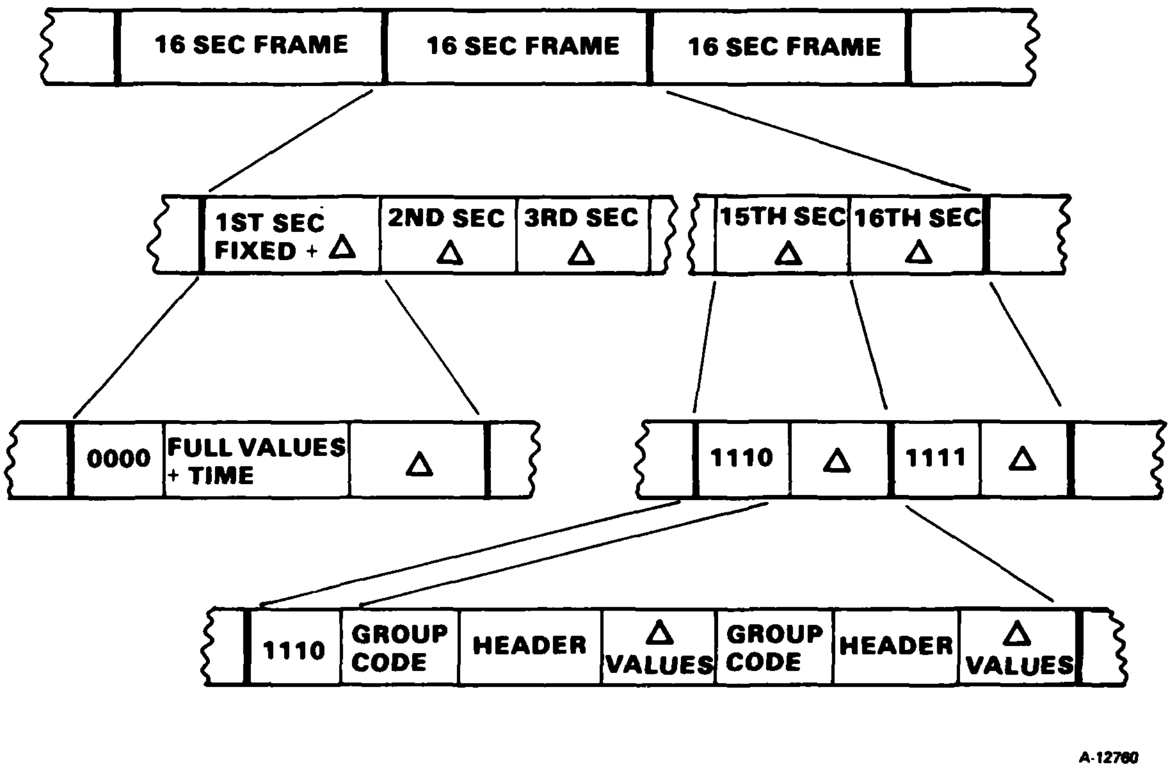


Figure 4-20. Proposed Data Format

bits would then be sufficient to represent each sample giving a data rate of 24 Kbit/sec. However, for decoding and for integrity full precision values would still have to be stored at regular intervals, increasing this data rate slightly.

This idea is taken to its limit in delta modulation where a 1-bit difference is used to code the signal. In the basic form of delta modulation, the sampling rate must be increased by a factor 8 in order to retain adequate quality (in order to ensure that no difference is greater than 1 bit). However, by using a variable step size that increases when the signal is changing rapidly and decreases when the signal is varying slowly, the data rate may be significantly reduced. Such continuously variable slope delta (CVSD) modulators are currently available in LSI technology and yield data rates of around 10 Kbit/sec for reasonable speech quality.

Vocoders attempt to exploit the redundancy in the speech waveforms by extracting the information bearing parameters of the speech signal. These parameters can be encoded at a much lower rate than is possible using the previous techniques without serious loss of intelligibility. At present, data rates of 2 to 3 kHz are possible for vocoders; and it is reasonable to assume that these figures will be improved in the near future, as well the technology to produce the circuitry in LSI form. Indeed, for the inverse operation of speech production from a memory, LSI chips are already available, requiring data rates of only 1200 bits/sec in order to drive them.

An important reservation must be made, however, relative to vocoders. Unlike the CVSD and other direct encoding techniques, vocoders are tailored to human speech patterns. Therefore, they will not be effective in reproducing other mechanical noises in the cockpit. These noises have sometimes been crucial in determining actual accident causes. For this reason, compression below CVSD rates of 10 Kbit/sec will result in a loss of data.

Figure 4-21 illustrates the memory and recording time relationships for the various encoding methods discussed above. With silence editing, the recording time could be approximately doubled assuming equal voice/unvoiced periods.

STORAGE TECHNOLOGY

Storage technology is very diverse with different storage methods developed for different applications. This review deals with those techniques particularly applicable to this study.

Digital data can be stored in many forms, but in general fall into two classes:

Volatile--Contents are lost when power is removed.

Nonvolatile--Retains contents when power is removed.

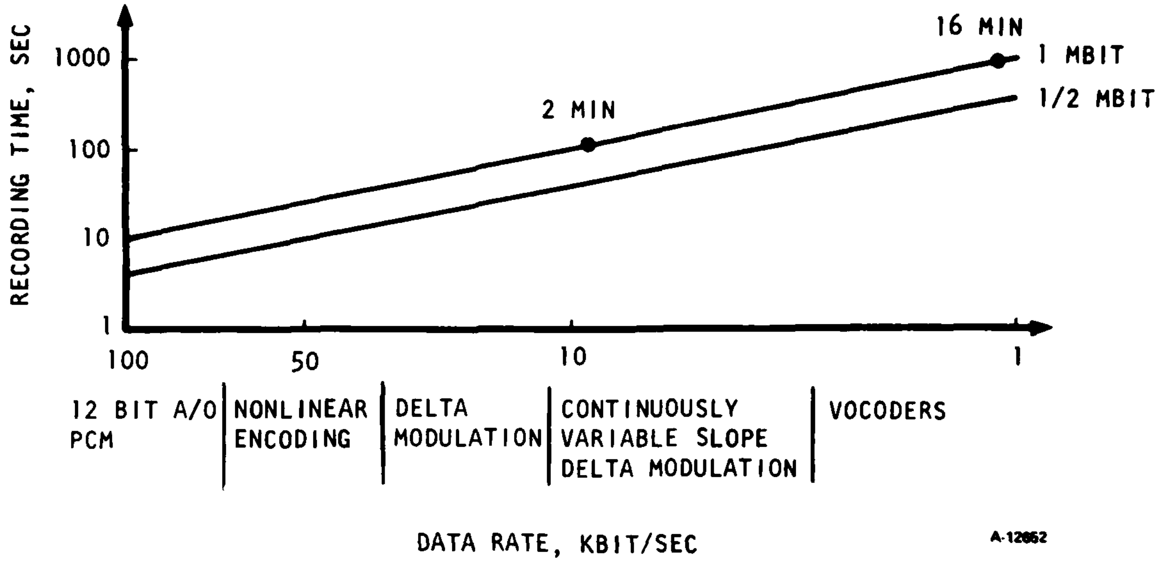


Figure 4-21. Data Rate vs Recording Time for Various Audio Technologies

For the purposes of a CSFDR, the memory module must satisfy the following conditions:

- Data retained under crash conditions
- Cost effective
- Small
- Lightweight
- Reliable
- Low power

Battery backed-up volatile memories were considered but rejected because of the nonavailability of a suitably reliable battery, for the conditions on a combat aircraft and those resulting from a crash. The nonvolatile storage technologies that will be considered are as follows:

- Semiconductor
- Magnetic bubbles

- Plated wire
- Magnetic tape
- Optical systems
- Magnetic disc
- Magnetic core

In the past, either magnetic tape, magnetic wire, or electromechanical scribing methods have been used to record aircraft data. With the advent of nonvolatile semiconductor memories, advanced optical memory systems, and magnetic disc memories, it is necessary to review these new technologies against existing storage media and assess which would be the most suitable for an advanced CSFDR system.

Semiconductor Memory Systems

Semiconductor memory technology falls into two main categories--metal oxide semiconductor (MOS) and bipolar. The first semiconductor memories built utilized bipolar technology. This provided high-performance systems, which were mainly used for smaller cache memory applications. The main drawbacks of bipolar memory technology are that the transistor geometries are large, giving low-density devices, and the power consumption is high. The need for lower power consumption led to the development of MOS memories, which give high-density, low-power, low-cost devices but with an increased access time. For the purposes of a CSFDR, access time is not a limiting factor since even for uncompressed data the maximum rate is 2 Kbit/s, and the advantages offered by MOS technology make it an attractive solution.

Bipolar Memory Systems

The storage element in a bipolar memory is the epitaxial transistor, which is small and has a fast switching speed due to its high transconductance. The main drawback of the epitaxial transistor is its low input impedance, which results in high power consumption. This, together with the fact that all bipolar memories are volatile, makes them unsuitable for use as a storage media in a crash survivable system.

Only one type of bipolar memory technology, integrated injection logic (I^2L), comes close to MOS memories in terms of cost, density, and performance. This is a relatively new technology that still results in a volatile memory, and it is not yet available in a suitably dense configuration.

MOS Memory Systems

MOS memories are based on the metal oxide silicon field effect transistor (MOSFET). These devices are available in both dynamic and static forms. In a dynamic device, the data is stored as a charge on a diffused capacitor; charge is trapped and provides a voltage bias, which turns off the MOSFET. Due to the fact that the leakage impedance of the storage capacitor is finite, the charge will slowly leak away and must be replenished periodically.

Static memories, however, store data by holding a transistor either on or off rather than as a charge and will thus maintain this state indefinitely while the device is powered. Static memories consume more power, are slower, and are less dense than the dynamic types. The following MOS memory types are available:

> PMOS (P-channel MOS)--This is the oldest of the MOS technologies, and the main drawback is that it requires multiple power supplies.
>
> NMOS (N-channel MOS)--NMOS was developed to overcome the low speed and multiple supplies required by PMOS. The resulting devices can operate on a single 5 v supply and are much faster than the equivalent PMOS device due to the much higher carrier mobility.
>
> CMOS (Complementary MOS)--CMOS memories use both NMOS and PMOS junctions to produce a device with very low power dissipation and low operating voltage (a CMOS device can operate with a supply voltage down to 1.5 v, which makes it very attractive for use with a battery to create a nonvolatile store). CMOS speeds are generally low compared to NMOS and if high speeds are required, then higher supply voltages need to be used. Although CMOS is essentially a volatile storage technology, nonvolatile CMOS memories will soon be available from Hughes Aircraft with a maximum density of 8 Kbit (1024 x 8). These devices are very fast, have a data retention time of 10 years at 100°C, and an endurance of 10^5 erase/write cycles, which is satisfactory for the current requirement. This makes the device suitable for the construction of a solid-state CSFDR; however, for a capacity of 1 MBIT, approximately 125 devices would be required. This large number of devices would lead to an unreliable and large system, so until larger CMOS memories are available, this technology does not offer an effective solution.
>
> SOS/MOS (silicon on sapphire MOS)--This memory technology was developed to produce a fast, low-power, high-density memory. The resulting devices have very high immunity to radiation, which makes them useful for military combat environments but at the present time they are expensive and no high-density nonvolatile memories are likely to be available.

CCD Memory Systems

The charge coupled device (CCD) memory consists of a series of charge-coupled shift register loops. Data is represented by the absence or presence of a charge and in order to stop the charge from leaking away, the data is sensed and regenerated by a continuous series of shift pulses.

CCD technology allows very low-power serial access memories to be constructed, but the fact that they are volatile makes them unsuitable for the CSFDR project.

Metal Nitride Oxide Semiconductor

The metal nitride oxide semiconductor (MNOS) process is used to produce electrically alterable read only memories (EAROM's), block oriented random access memories (BORAM's), and line addressable random access memories (LARAM's). The data given below applies to all these devices. MNOS was developed to overcome the volatility shortcomings of MOS memories, and the resulting device is both fast and nonvolatile.

Data is stored as a charge in the interface layer between the silicon nitride and silicon dioxide interface. The presence of this charge lowers the threshold voltage of the sense transistor so that when it is interrogated the storage transistor turns on. If the charge is not present, then the transistor does not turn on when interrogated.

These trapped charges are quite stable and will remain at a determinate level for up to 10 years. Figure 4-22 shows the decay of the positive and negative threshold levels with respect to time, and it can be seen that the threshold window remains for at least 3×10^8 sec (10 years).

Alteration of the contents of an MNOS memory cell differs from conventional R/W memories in that the old contents must first be erased, and then the new contents written to the cell. This leads to a lengthly double write cycle if the cell has previously been written to, and this can lead to a write time in

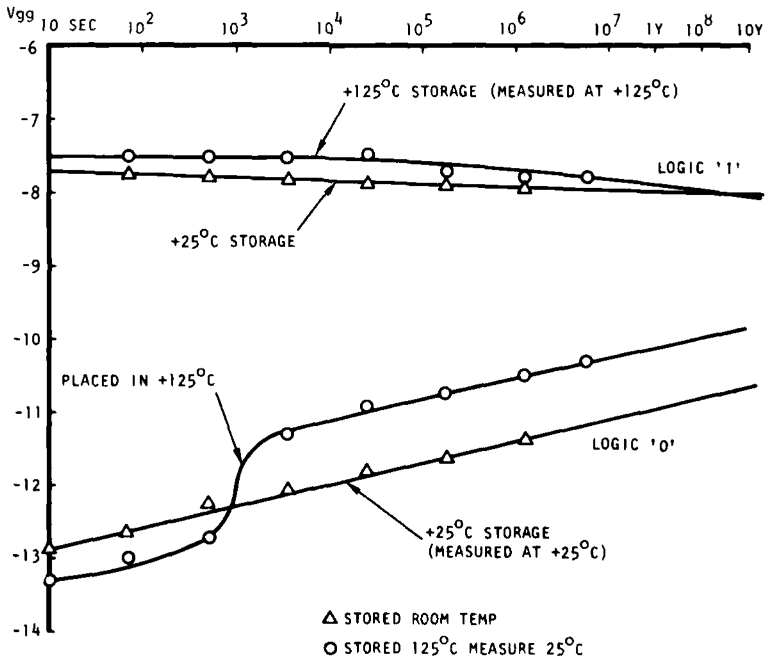


Figure 4-22. Typical Retention Prediction Plot for GI3400

the region of hundreds of milliseconds. The reason for this lengthy write time (and erase time as erase is simply to write all zeros), is that in order to store a large enough charge to last 10 years or more, the stored charge must be relatively large.

The decay rate of the trapped charge is dependent, not only on the leakage rate within the device but also on:

- The device temperature
- The ambient radiation levels in which the device is operating
- The number of erase/write cycles that the particular memory cell has been subjected to

The charge decay rate, being a direct function of the number of erase/write cycles that the cell has been subjected to, limits the useful life of the device since it will not then retain its data for a useful time. Figure 4-23 gives an indication of the charge decay rate after 1, 10^4, 3×10^4, and 10^5 erase/write cycles, and it can be seen that the device is approaching the end of its useful life after 10^5 erase/write cycles. This figure shows a basic limitation of all MNOS devices due to the erosion of the oxide layer that is used to store the charge. If the layer is made thicker, then the life will be longer, but the amount of charge needed to be stored will be larger and hence the write and erase time longer. The thickness of the oxide layer therefore is an endurance/write time tradeoff.

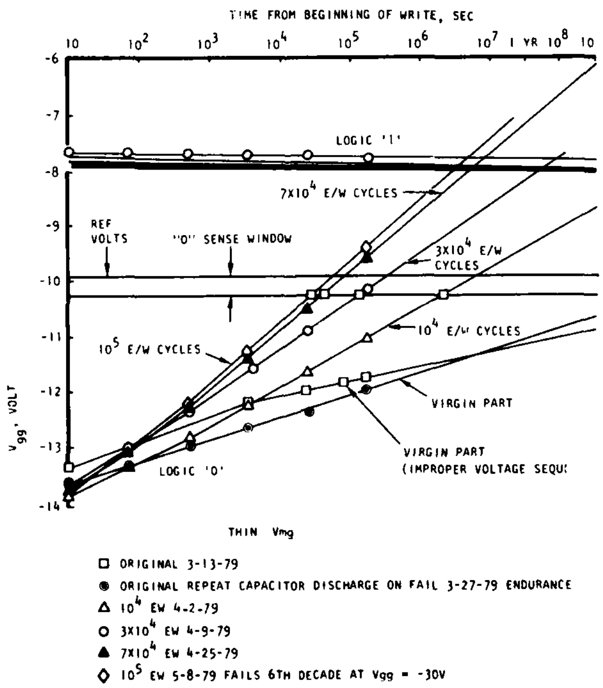


Figure 4-23. Endurance of GI3400 (Relatively Thin Nitride)

BORAM's are produced by Sperry-Univac and Westinghouse Defense and Electronic Systems Center. The devices manufactured by Sperry-Univac are not available to other contractors and will not be considered further.

The devices manufactured by Westinghouse (8 Kbit at present) are only available packaged into a module and not as individual units. Multichip hybrid microcircuits are produced with 16 devices in a package. This package is then incorporated with the necessary control circuitry in a memory module. The availability of increased capacity modules is predicted by Westinghouse and shown below:

Year	Device Capacity	Module Capacity
Present	8 Kbit	131 Kbit
Late 1981	32 Kbit	0.5 Mbit
Late 1983	131 Kbit	2 Mbit

Westinghouse is not a major semiconductor house and is selling its proprietary BORAM devices into a limited number of programs. The indication therefore is that the device prices will not fall as fast as those from major semiconductor houses (e.g., The Intel Corporation E^2PROM described below). It seems unlikely that a second source will be available.

In an attempt to overcome the long write time and low density penalties associated with MNOS memories, the Intel Corporation has developed an advanced MOS process, which has been named HMOS-E. This will be described in the following section.

Intel HMOS-E Process

The HMOS-E process was developed by the Intel Corporation to produce the floating gate tunnel oxide (FLOTOX) nonvolatile memory cell. Unlike the MNOS memories previously described, which rely on charge storage within a nitride layer, the Intel device relies on charge storage on a floating gate of polysilicon. The advantages of this process are based on the fact that the floating gate can be made very small. This means that:

(a) A very dense device can be produced.

(b) Because the electrons have to tunnel through an oxide layer only 200 A thick to reach the floating gate, the resulting device is very fast (300 ns maximum access time for an MIL-STD device).

(c) The device has excellent data retention characteristics over a wide temperature range. The device will retain its data for 20 years at 125°C with an absolute maximum data retention threshold of around 150°C.

(d) There is no limit to the number of times a memory cell can be read; unlike MNOS, which has a read limit of around 2×10^{11} before a refresh is required.

The HMOS-E E^2PROMS presently available are 16 K (2 K x 8) dual-in-line packaged, commercial temperature range devices. It is predicted that by mid-1981 MIL-STD versions will be available. Chip carrier versions for high-density memory systems should be available by late 1981.

Higher density devices are under development, with a 64 K device scheduled for release in 1983 or 1984 and a 131 K device using an enhanced HMOS-E process available around 1985. Other companies are likely to follow the lead taken by Intel in producing an EEPROM that is pin compatible with the industry standard 2 K x 8 EPROM, and this will ensure a second source for the device.

EBAM Memory Systems

Electron beam addressable memory (EBAM) or beam addressable MOS (BEAMOS) memory systems were developed for mainframe computer applications where it is desirable to have a large, low cost per bit and fast access memory. The actual storage medium is an unstructured semiconductor plane, and each memory bit is accessed using an electron beam. The semiconductor storage planes are mounted in small cathode ray tubes, and the addressing is accomplished by deflecting the beam.

The disadvantages of this new, unproven technology are that the CRT's are bulky and require costly beam deflection circuitry and power supplies. Furthermore, the very fast access speeds attainable with this form of memory are not specifically required for the CSFDR. The nature of the memory means that it would be very difficult to crash protect.

Optical Memory Systems

Optical memories were developed for mainframe computer mass storage applications. The storage medium is a holographic plane that is interrogated using a laser. A very large amount of data can be stored in this way, but it is very bulky and susceptible to vibration. This is a new technology and has not yet been proven in the field, but it is unlikely to suit the CSFDR application as the fast access and very dense storage are not prime requirements. The problems involved in designing such a system that would operate in an aircraft environment and survive a crash are severe.

Bubble Memory System

Bubble memory technology was first discovered in 1967, and the first devices were available in 1975 with a capacity of 16 Kbit. Today, the state-of-the-art device has a capacity of 1 Mbit and a 4-Mbit device is expected to appear in 1982 or 1983.

In a bubble memory, data is represented by magnetic bubbles, which are produced in a film of magnetic material that has been epitaxially grown. An external magnetic field is applied to the magnetic substrate, and this causes the magnetic bubbles to line up with the field along a single axis. Data is represented by the presence or absence of the magnetic bubbles.

In order to access a particular location in the memory, the magnetic bubbles are shifted around within the magnetic substrate. This is achieved with islands of soft magnetic material deposited on the magnetic film and by applying a rotating drive field. The magnetic polarities of these islands shift around in cadence with the rotating magetic field, and this steers the bubbles from island to island.

Within each magnetic bubble memory, the bubbles are rotated in major and minor loops and at a specific location in the loops data is read or written. In order to read data from a bubble memory, it is necessary to sense the presence or absence of a bubble, and this is done by stretching the bubble and then passing it under a permalloy magneto-resistive detector. The change of impedance within the detector is sensed and amplified, and this signal is fed to the read electronics. The writing of data is accomplished by using a small current loop. If a particular bubble is brought under the current loop, bubbles can be created by applying a pulse of current in opposition to the memory's static bias field. Similarly, if current is pulsed in the same sense as the bias field, bubbles can be annihilated or erased.

Because data is represented by a magnetic rather than an electric signal, the bubble memory is a nonvolatile medium and its contents are retained virtually indefinitely under normal conditions. However, just as a permanent magnetic loses its strength when heated or shocked, bubble memories can lose their contents under the same conditions. The temperature sensitivity of a particular bubble memory can be controlled by suitable selection of the materials involved in the manufacture of the magnetic garnet material, and, in general, an 80°C span is possible with limits of -20° to +80°C. This makes the use of bubble memories for a military environment limited without bulky and expensive environmental conditioning equipment. Also, extreme shock can cause data in a bubble memory to be lost. It is therefore desirable to protect the memory in a module against the severe shock levels experienced in a crash, and this causes an increase in protection hardware.

Despite these shortcomings, however, the bubble memory has advantages for data recording and with 4-Mbit devices available soon it will be possible to produce a compact high-density recording module for use in a limited environment only, probably for systems in which the memory is not exposed to high shock levels.

Magnetic Core Systems

Magnetic core memories were first developed for use as program storage in mainframe and mini-computers. They are now available in compact modules for use over the temperature range -55° to +105°C and are used typically for computer program and data storage. However, the high power consumption and manufacturing cost together with complex drive electronics, loss of data at temperatures above 105°C, and large size make magnetic core memories unsuitable for use as a storage media in a CSFDR.

Plated Wire Memories

Plated wire memories were developed as a high-performance magnetic core substitute. They provide the same sort of performance as magnetic core, but with better radiation immunity and higher speed at the expense of cost. This makes the use of plated wire memories unsuitable for the CSFDR application.

Magnetic Discs

Magnetic discs were first developed as a successor to the magnetic drums that were used on the first computers. Today discs are still used as an online data source for mainframe computers, and a derivation of the original rigid (or hard) disc has been the floppy disc. This is available in either the 5-in. (mini-floppy) or the 8-in. floppy format. Both are widely used for program and data storage on mini-computers and development systems. Typical capacities of the floppy disc are 1.2 Mbyte for the 8-in. version and 500 kByte for the 5-1/4-in. version.

While the floppy disc forms a convenient, cheap, and reliable data storage media for commercial use, it has not been exploited for military use. This is due to the fact that the storage medium is difficult to protect from the adverse military environment, and the disc drive is susceptible to the vibration and shock levels found in most military applications.

A recent development of the rigid disc has been the Winchester technology disc, which is gaining popularity for mass storage of data on mini- and micro-systems. This disc is available in 5-1/4-in., 8-in., or 14-in. formats with capacities of 2 MByte, 10 MByte, and 700 MByte, respectively. The drives employ single or multiple discs and a moving low-mass head in a sealed environment. Because the disc is not removable and the environment is sealed, a very high density is possible with low error rate and this makes the medium ideally suitable for large quick-access data bases. One small airborne 2.5-MBit disc memory system is presently available. The disc unit itself is 9 by 6 by 5 in. and weighs 9 lb, but because of the expense of making the system perform over the military temperature range, the system is very expensive, with just the disc drive alone costing $7,000 to $10,000. For this reason, and the fact that the very fast access times are not required, the disc drive is not suitable for the CSFDR.

Magnetic Tape

Magnetic tape is a most attractive storage media for the CSFDR application. Magnetic tape has been used for recording crash data on military and commercial aircraft for many years and has the advantage that it is a proven technology. With careful selection of the tape material and the protective case, a recorder can be made that will survive the high temperatures and shocks associated with a crash, and have a large enough capacity to be able to record all the crash data, both parametric and audio, for any reasonable duration several hours before the crash.

Cassette and Cartridge Recorders

Magnetic tape in either 1/4 in. or 1/2 in. widths can be packed into cassettes or cartridges to provide a self-contained removable storage medium. This system is often used in applications requiring the removal of data from an aircraft after each flight; for example, maintenance and performance monitoring. The disadvantages of cassette and cartridge recording systems are that the manufacturing tolerances of the interchangeable cassettes can affect the tape guidance, and the tape environment is not controlled, which does give an inherent increase in error rate.

Another form of magnetic tape recording is the continuous loop system. This offers continuous recording of data so that at any given time the recorder holds approximately 30 min of data. The design of such a recorder is critical in order to achieve correct tape guidance in a harsh environment, and only a few manufacturers have succeeded in producing a successful design.

Reel-to-Reel Recorders

Reel-to-reel magnetic tape recorders have been used for several years to record data and voice on aircraft. They appear in many forms and, depending on the exact application, tape width, number of tracks, tape speed, tape length, tape material, and data rate, can all be varied to suit the specific application. Reel-to-reel recorders are currently used for crash and maintenance recording and have a typical capacity of the order of 15 MBit. Recorders for civil transport aircraft, built to ARINC 573, have a capacity of 70 Mbit. The data rate can be fixed or variable depending on the incoming data rate, and analog data can be mixed with the digital data on different tracks.

The magnetic tape recorder is a flexible, high capacity, serial recording device. The development and production of a relatively low-cost tape transport for this application, which would have an MTBF of over 4000 hr and would meet the size and weight constraints, would offer very little technology risk.

For the purpose of a crash data recorder, the capacities offered by a magnetic recorder are large. A solid-state memory can be a more cost effective solution, depending on the data capacity required (which is dependent on the system configuration) and on the in-service timescales. However, if maintenance data is required, the high capacity NGL1203V000 transport magazine provides an excellent solution. This unit is installed on the F-18A Hornet and has a calculated MTBF of over 4000 hr. To date, no failures have been reported in over 3000 flight hr. The cost is 0.1 cent per bit for the tape transport, together with its electronics, and about 0.05 cent per bit for the tape transport only.

A comparison of the characteristics of different storage media is shown [illegible] 4-8.

[illegible]

[illegible] memory module forming part of a CSFDR system [illegible]. The protection, in the event of

TABLE 4-3

COMPARISON OF THE CHARACTERISTICS
OF DIFFERENT STORAGE MEDIA

Medium	Availability	Density	Speed	Temperature Range		Read Access Retention	Endurance	Retention
				Working	Storage			
Tape module	Good	~15 MBit	Poor random access Good sequential access	-55° to +71°C	+300°C	Virtually unlimited	Virtually unlimited	Indefinite (BER will increase with prolonged R/W
Bubbles	Good	1 MBit	Poor random access Good sequential access	-20° to +80°C	+80°C	Not affected	Unlimited	Indefinite
EEPROMS	Increasing	16 KBit	Good	-55° to +125°C	~+150°C	Not affected	10^4 E/W cycles at present 10^5 E/W soon	10 to 20 years
EAROMS	Good	8 KBit	Medium	-55° to +125°C	~+160°C	2×10^{11} read accesses	10^5 E/W cycles	10 years
Magnetic core	Medium	64 K	Medium	-55° to +105°C	+105°C	Data is destructively read--therefore it must be rewritten after each read	Unlimited	Unlimited
Magnetic disc	Poor	~10 MBit	Medium/good	-55° to +125°	-	Virtually unlimited	Virtually unlimited	Indefinite (BER will increase with prolonged R/W

a crash, has first to prevent the storage medium from degrading during the impact. This impact can cause high shock levels and the likelihood of penetration by aircraft structural members. This can then be followed by a fire or an immersion in fluids likely to be found within an aircraft or used in fire fighting.

Subsequent to the crash the memory module has to be recovered and the data extracted for analysis. During normal flight operation the storage module is required to operate in an inaccessible part of the aircraft and any self-generated heat should not degrade the memory.

Several methods have been employed to protect crash recorders. The majority of these provide an external armor plate, to withstand any crushing and penetration forces. Within this armor plate the thermal protection is either 3/4-in.-thick insulation material or a thin thermal insulant with a heat sink inside. This heat sink jacket contains a material that melts or vaporizes. The memory module is then secured within this enclosure.

Other units have been manufactured utilizing a container formed from an ablative compound. This compound provides both mechanical and thermal protection.

During the course of this study the latest technologies have been investigated, particularly those for thermal protection. Information was obtained on the latest ablative materials designed for use as heat shields; on intumescent coatings, which is a relatively new technology; and on thermal insulation materials.

In the past, Normalair-Garrett Limited has designed and built crash protected recorders utilizing both thermal insulants and ablative compounds as the thermal protection. The design of a protection system utilizing a heat sink of a material that melts or vaporizes is fairly straightforward but the use of intumescent coatings for thermal protection is more complex.

So that we could fully understand the problems associated with the use of an intumescent coating that is applied on the outside of any crash protected enclosure and as such requires to withstand any penetration force, it was decided to carry out tests on a representative case.

Although subsequent information indicates a shorter fire test might be applicable, tests were carried out to the TSOC51a requirement for both the penetration and fire. The results are shown in Figures 4-24, 4-25, and 4-26. Appendix J provides further details.

Thermal insulators for this type of application utilize the extremely low thermal conductivity of air. They consist of porous materials that have low mechanical strength, the air being trapped within each of the cells. If crushed they lose most of their insulating properties. Figure 4-27 shows typical conductivities for high-temperature insulation.

PENETRATION RESISTANCE:

TESTING CARRIED OUT ON 2 SEPARATE CASES MANUFACTURED FROM 0.080 IN. THICK STAINLESS STEEL (18-8), WITH EXTERNAL TESTING SURFACE COATED WITH 0.180 IN. THICK INTUMESCENT COATING.

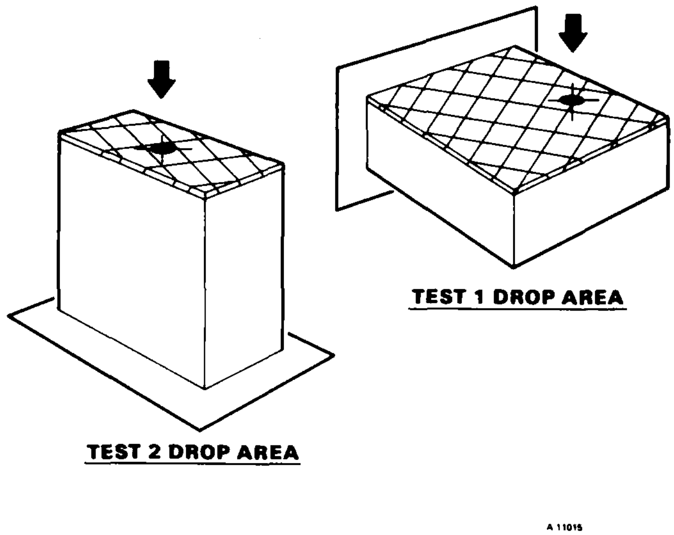


Figure 4-24. Testing Penetration Resistance

FIRE TEST

A FIRE TEST WAS CARRIED OUT ON THE DAMAGED SURFACE OF TEST CASE NO. 2

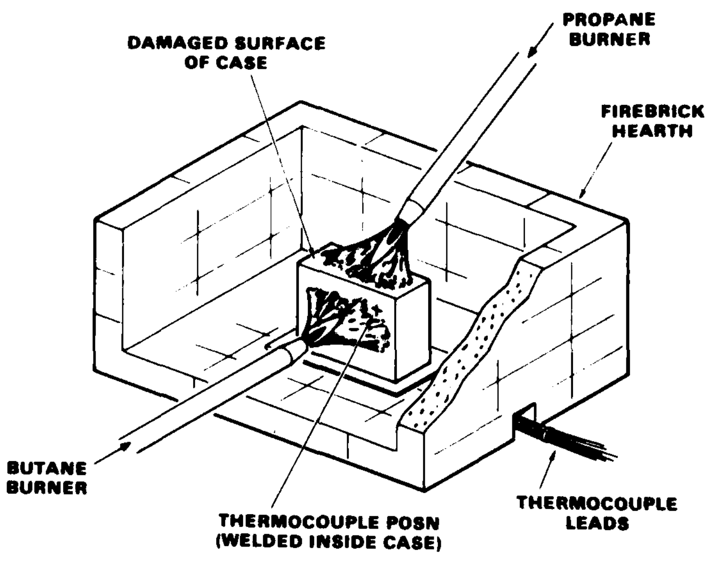


Figure 4-25. Fire Test

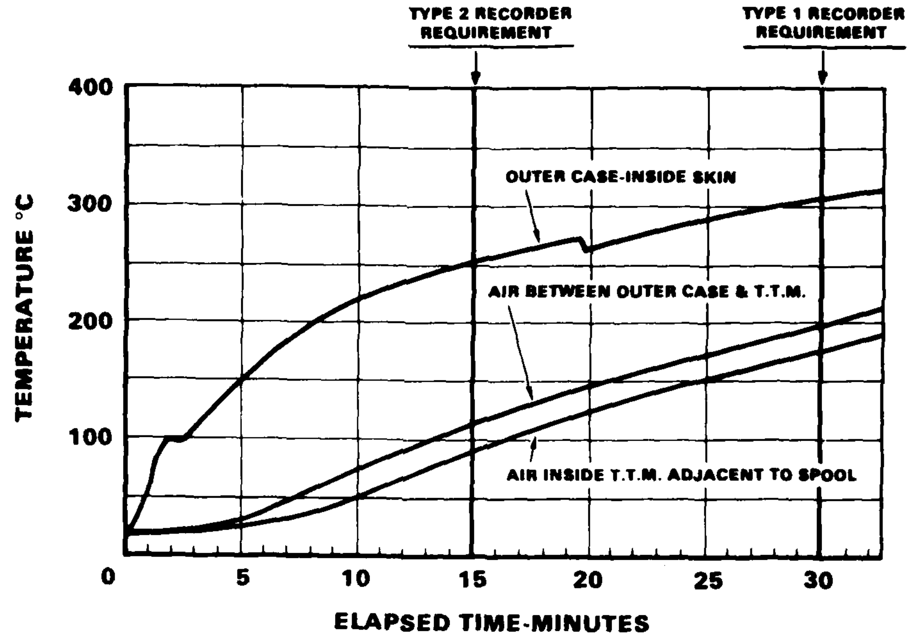


Figure 4-26. Fire Test to Specification FED TSO-C51A

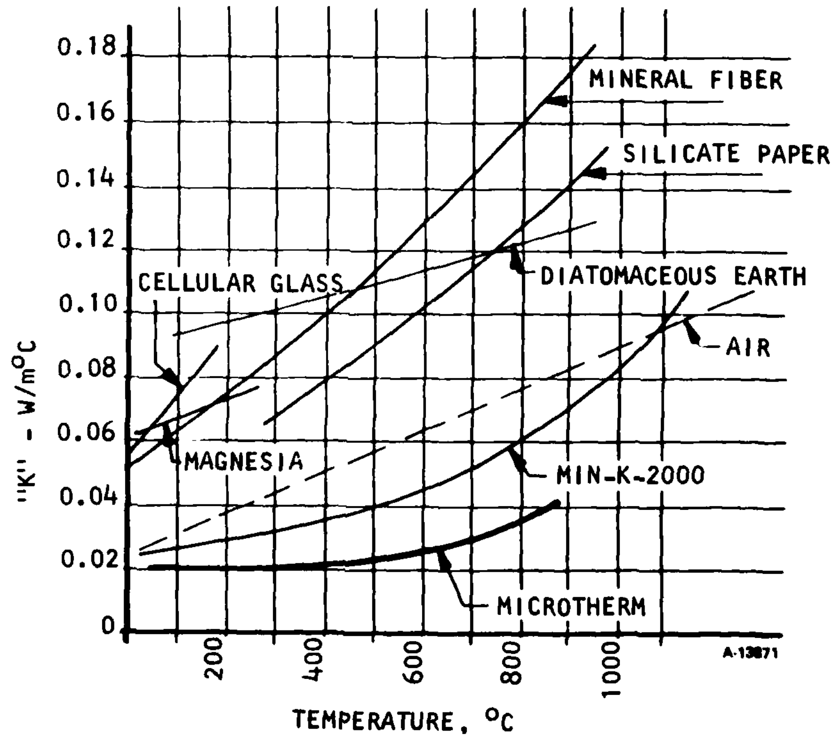


Figure 4-27. Conductivity of High-Temperature Insulation

The latest ablative materials were developed for use with heat shields of space vehicles. An ablative material protects the unit contained within from the effects of a fire by charring. In charring heat is absorbed, and the heat absorbed is proportional to the weight lost.

Intumescent materials designed for protection from hydrocarbon fires are stable materials until attacked by fire. The material then swells against the heat source, and the surface erupts to reflect and radiate the heat back (see Figure 4-28).

Tables 4-4 and 4-5 give calculated temperatures of a steel plate coated with an intumescent material when subjected to fire.

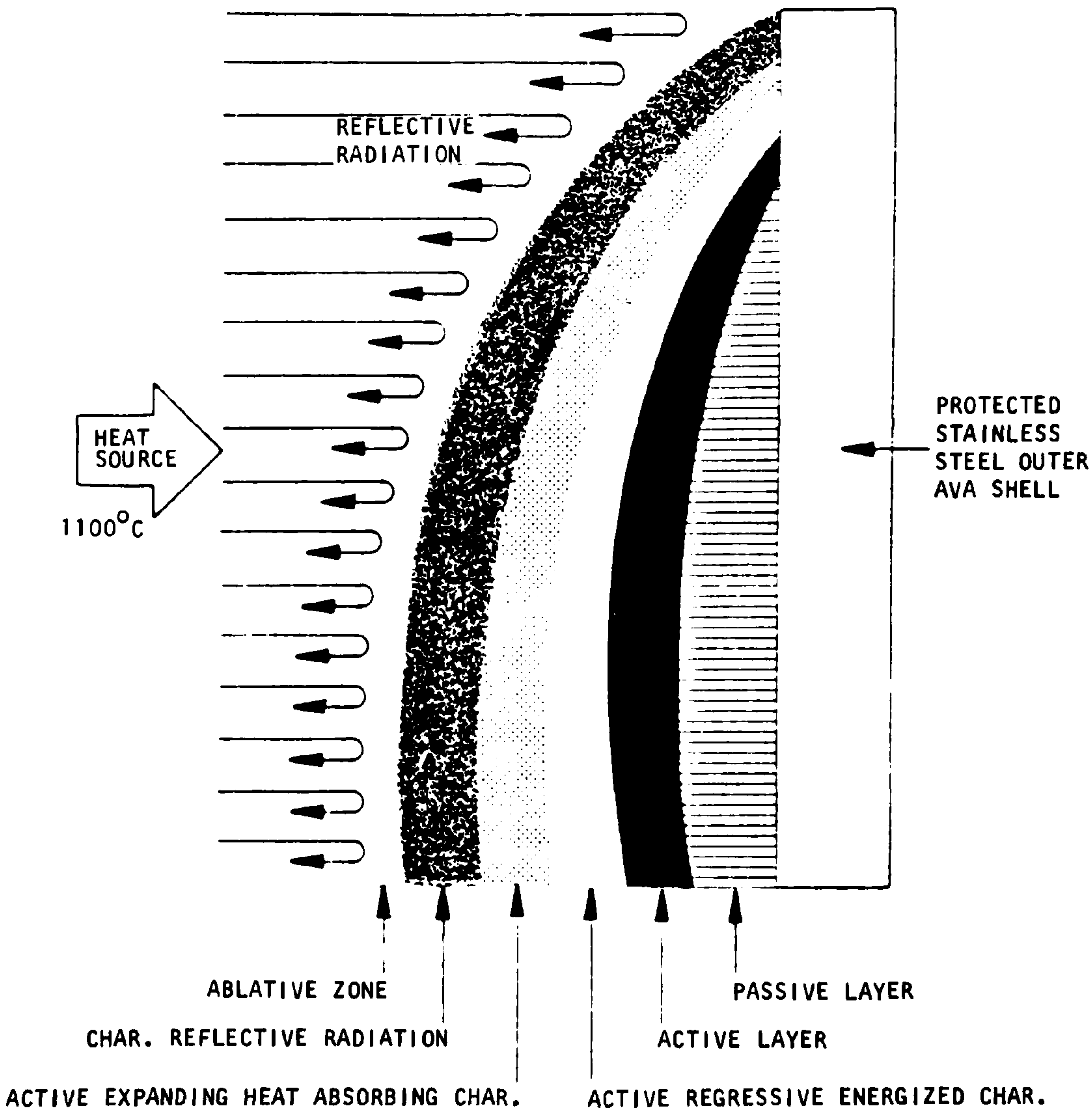


Figure 4-28. Intumescent Coating Breakdown

TABLE 4-4

TEMPERATURE OF 2-MM STEEL COVERED BY FIREC INTUMESCENT
(AFTER 15 MIN FLAME TEMPERATURE 1200°C)

FIREC Intumescent Thickness, mm	Steel Temperature, °C
1.0	425
1.5	375
2.0	340
2.5	320
3.0	300

TABLE 4-5

TEMPERATURE PROFILE OF 2-MM STEEL COVERED BY 1-MM FIREC
INTUMESCENT (FLAME TEMPERATURE 1200°C)

Time, Min	Steel Temperature, °C
0	20
1	225
2	275
3	295
4	310
5	325
10	385
15	425

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SECTION 5

TECHNOLOGY TRADEOFFS

DATA STORAGE REQUIREMENTS

Configurations I and II

The information gathered from accident investigation authorities indicated a range of data storage durations. The times required were dependent upon whether preflight and takeoff data is recorded and maintained in the store for the entire flight. A range of compression ratios is indicated in Section 4.

Using the parameter lists, accuracies, and resolutions from Table 3-2, a range of data storage requirements can be generated, as shown in Table 5-1. Table 5-1 includes the requirements for audio recording for both analog and digital recording methods. The capacity requirements for digital recording of audio assumes the use of continuously variable slope delta modulation (CVSD), with a data rate of 8 Kbit per sec.

TABLE 5-1

RANGE OF DATA STORAGE REQUIREMENTS

	Parametric Data			Audio			
						Digital	
Configuration	Storage Time	Compression Ratio	Data Capacity	Storage Time	Analog Recording Duration	Silence Editing Ratio	Data Capacity
I	15 min	10	180 Kbit	10 min	10 min	1	4.8 Mbit
		5	360 Kbit			4	1.2 Mbit
	1 hr	10	720 Kbit	30 min	30 min	1	14.4 Mbit
		5	1440 Kbit			4	3.6 Mbit
II	15 min	8	110 Kbit	10 min	10 min	1	4.8 Mbit
		4	225 Kbit			4	1.2 Mbit
	1 hr	8	450 Kbit	30 min	30 min	1	14.4 Mbit
		4	900 Kbit			4	3.6 Mbit

Table 5-1 has been derived using the following compression algorithms. In order to maintain the accuracy and information of the raw data, reversible compression algorithms would be used. By use of delta coding techniques a factor of 2 compression would immediately be available including the penalty for the requirement to store full precision values at regular intervals in order to be able to reconstruct the signal and to ensure data integrity.

With a zero-order prediction algorithm a further factor of 2 compression on signals that are rapidly varying and a factor 10 on those that are changing slowly would be possible. If it is assumed that not all signals will fluctuate rapidly at the same time but that the available compression will be the average of these two extremes, a factor 6 is achievable. The zero-order predictor represents a very small overhead in processing requirements, the main penalty being in the necessity for a variable store format. Such a format effectively creates an expansion by a factor 2 due to the necessity for tagging each variable. Since with the delta encoding and the predictor a compression of 12 is available, this overhead is acceptable, reducing the overall compression to 6.

Initial investigations indicate that a further 30 percent compression may be possible using entropy encoding techniques. The penalty is an increase in processing and memory requirements (for the code book) and increased format complexity due to the variable length values. It is recommended that these encoding techniques and the possible compression to be obtained due to the interrelationship between parameters be investigated using flight data to determine the actual degree of compression achievable. To define the most likely compression ratio it has been assumed that the figures quoted above can be obtained. For configuration II, however, which is a system requiring no development of technology, the use of entropy encoding has not been assumed. This configuration also requires only minimum data retention, which is 10 to 15 min plus preflight and takeoff data. For configuration I, however, it will be advantageous to record 30 min of data. The storage capacities are therefore as given below.

Configuration	Raw data, bits/s	Data retention, min	Total data, bits	Compression ratio	Compressed data, bits
I	2 K	30	3.6 M	8 to 9	420 K
II	1 K	15	900 K	6	150 K

If audio is recorded digitally, the data storage required is 2.4 Mbit assuming 10 min duration, the minimum requirement, and a silence editing ratio of 2, which should be obtainable. For analog recording the minimum duration of 10 min is required.

Standardization

If standardization is considered for a large range of aircraft including bombers and transports, it is a requirement to record voice and data for longer durations with an increased number of parameters. For multicrewed aircraft at least two channels of voice data would be required. These requirements are summarized below (information is given for digital recording of audio).

	Raw data, bits /s	Data retention, min	Total data, bits	Compression ratio	Compressed data, bits
Data	2.8 K	90	15 M	8 to 9	1.8 M
Audio	2 channels	30	30 M	Silence editing 2	15 M

Configuration III

Recording of maintenance data, assuming a high level of processing onboard the aircraft, requires approximately 2 Mbit of data per flight for a short-duration fighter-type aircraft. This figure is based upon experience of the maintenance system on the U.S. Navy Hornet.

This figure might increase to 6 Mbit for a longer duration aircraft and to perhaps 16 Mbit for bomber and transport aircraft. A lower level of onboard processing will also increase capacity requirements.

Range of Data Capacities

The following is a summary of the data capacities developed above.

Configuration I	Data Audio	420 Kbit 2.4 Mbit
Configuration II	Data Audio	150 Kbit 2.4 Mbit
Multiengined long duration aircraft	Data Audio	1.8 Mbit 15 Mbit
Maintenance data (additional to crash data)	Low capacity Medium capacity High capacity	2 Mbit 6 Mbit 16 Mbit

These capacities can be provided as individual memory modules for crash data, audio, and maintenance, but would be better provided by storing a combination of some or all types of data in one memory module. This gives a range of capacities to be considered as follows.

160 Kbit (150 Kbit)	Configuration II crash data only
1/2 Mbit (420 Kbit)	Configuration I crash data only

3 Mbit	Configuration I crash data and audio
6 Mbit	Medium capacity maintenance
16 Mbit	High capacity maintenance

Other specific capacities are close enough to one of those listed above to make separate consideration unnecessary.

SOLID-STATE MEMORY

The memory technology survey shows that the prime contenders for use in a solid-state memory are the BORAM devices produced by Westinghouse and the Intel Corporation E^2PROM devices produced by the HMOS-E process.

Figure 5-1 shows the projected cost of the Intel devices packaged in chip carriers for both the 16-Kbit device (M 2816) and the 64-Kbit device scheduled to be available in 1983.

These chip carriers can be packaged four in a 28-pin dual-in-line package. The projected costs of this form of package, together with the cost per bit is shown in Figure 5-2.

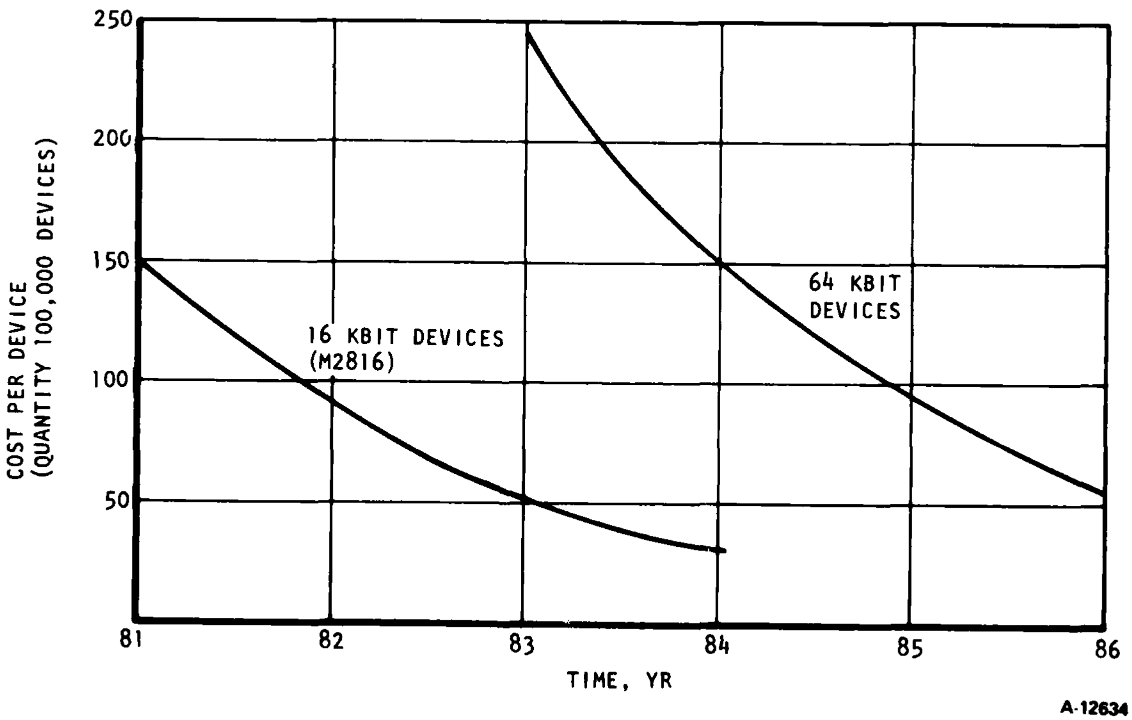

Figure 5-1. Projected Cost of Intel E^2PROM Devices

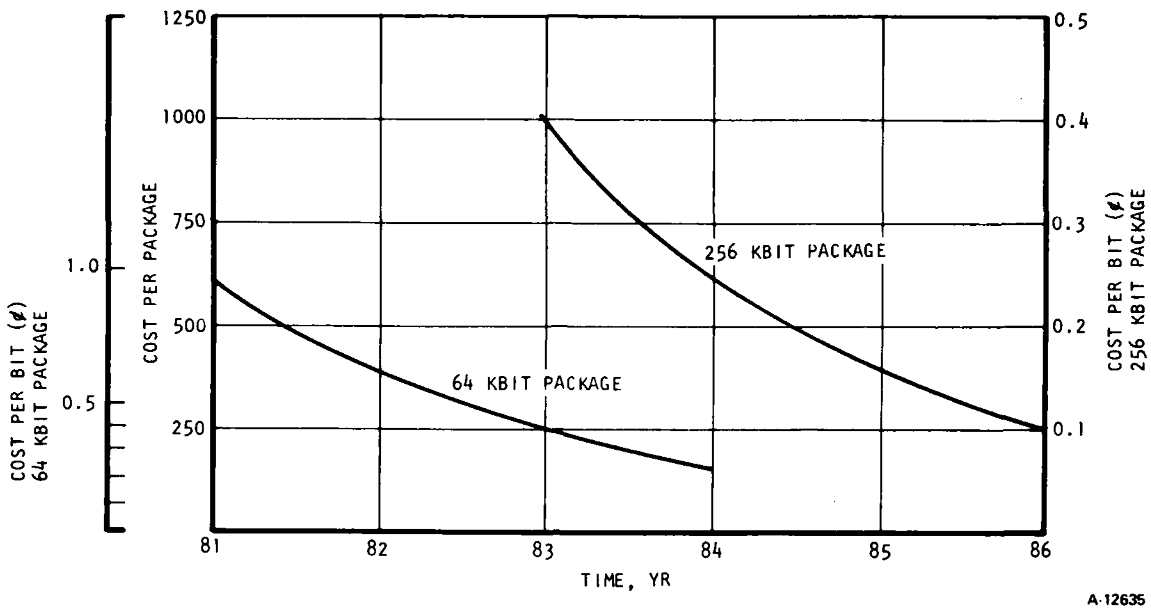

Figure 5-2. Projected Cost of Intel E^2PROM Devices in High-Capacity Packages

The Westinghouse (1/2 Mbit) module is projected to reduce to a cost of 1 cent per bit when total sales reach 100,000 modules. Thus, the Intel devices show greater promise of low cost. This technology also has the advantage that it is very likely to be second sourced, whereas the Westinghouse units are not (see Section 4).

DATA ACQUISITION AND PROCESSING

Analog-to-Digital Conversion

The system requirements for the analog-to-digital conversion are as follows:

- Maximum resolution 11 bits
- Worst-case accuracy 0.1 percent
- Conversion speed 1 ms per conversion

Although on the subject aircraft all the high accuracy parameters are available on the 1553 bus, in order to provide for other aircraft where they may not be available on the bus so that a standardized equipment may be designed, 0.1 percent accuracy should then be the design aim for the converter.

These requirements are best obtained using a 12-bit successive approximation analog-to-digital converter.

PROCESSOR

For configuration I where fairly complex compression algorithms will be used (entropy encoding), a 16-bit processor is required if they are proven to give the predicted compression ratios. These devices are becoming much more cost effective as their prices reduce with the manufacturers learning curve and sales increase. The exact processor type will be chosen later, in a development program.

In a configuration II system the compression used will be more simple, and can be achieved with a lower cost fast 8-bit processor. The choice has the additional advantage that the higher risk associated with 16-bit devices, which currently either have hardware or software bugs, or are difficult to obtain to a military specification, is eliminated.

The longer timescales associated with a configuration I system will reduce these risks to an insignificant level.

1553 BUS INTERFACE

The interface chip set, designed by Smiths Industries in the United Kingdom and discussed in Section 4, will not operate correctly on a 1553A bus due to differences in timings, status bit, and mode code assignments. Therefore, a design of an interface based on the Harris LSI device has been chosen.

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CRASH SURVIVABLE FLIGHT DATA RECORDING SYSTEM STUDY.(U)
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SECTION 6

CANDIDATE SYSTEM DEVELOPMENT

CONFIGURATION I

Configuration I calls for the maximum number of parameters to be recorded for the maximum useful time. This is the optimum solution for a crash survivable flight data recorder (CSFDR) that would be used in a post-accident analysis.

The block diagram of this system is shown in Figure 6-1, and it breaks down into five sections as follows:

(a) Signal conditioning and digitization

(b) 1553 data bus remote terminal unit

(c) Microprocessor and associated support

(d) Crash survivable memory module

(e) Power supply unit

The system will be comprised of two separate units comprising the data acquisition and processing unit (DAPU) and the crash survivable memory module (CSMM). The reason for two separate units is that the ideal position within an aircraft for a CSMM is as far aft as possible. The data transfer and control of the CSMM from the DAPU will be carried out using a dedicated data link. The DAPU should be as close to the electronic equipment bay as possible, as this is where most signals are available.

The CSMM will probably be in an inaccessible position. This necessitates that the data link between the two units is a bidirectional data link. This would allow for any built-in test functions to be carried out so that fault isolation between the data acquisition and processing unit and the crash survivable memory module is accomplished.

The DAPU interfaces with existing aircraft systems that supply the data inputs. There will be two types of data formats--the analog signals and the serial digital data bus (1553).

The interfacing to these systems will be designed such that the CSFDR will not degrade any aircraft functions. The serial digital data interface will conform to the MIL-STD-1553 that is fitted to each candidate aircraft. There are various derivatives of the MIL-STD-1553, and the same aircraft may have different standards depending on the aircraft build state.

Analog interfacing can be a problem if certain areas are neglected. These areas are as follows:

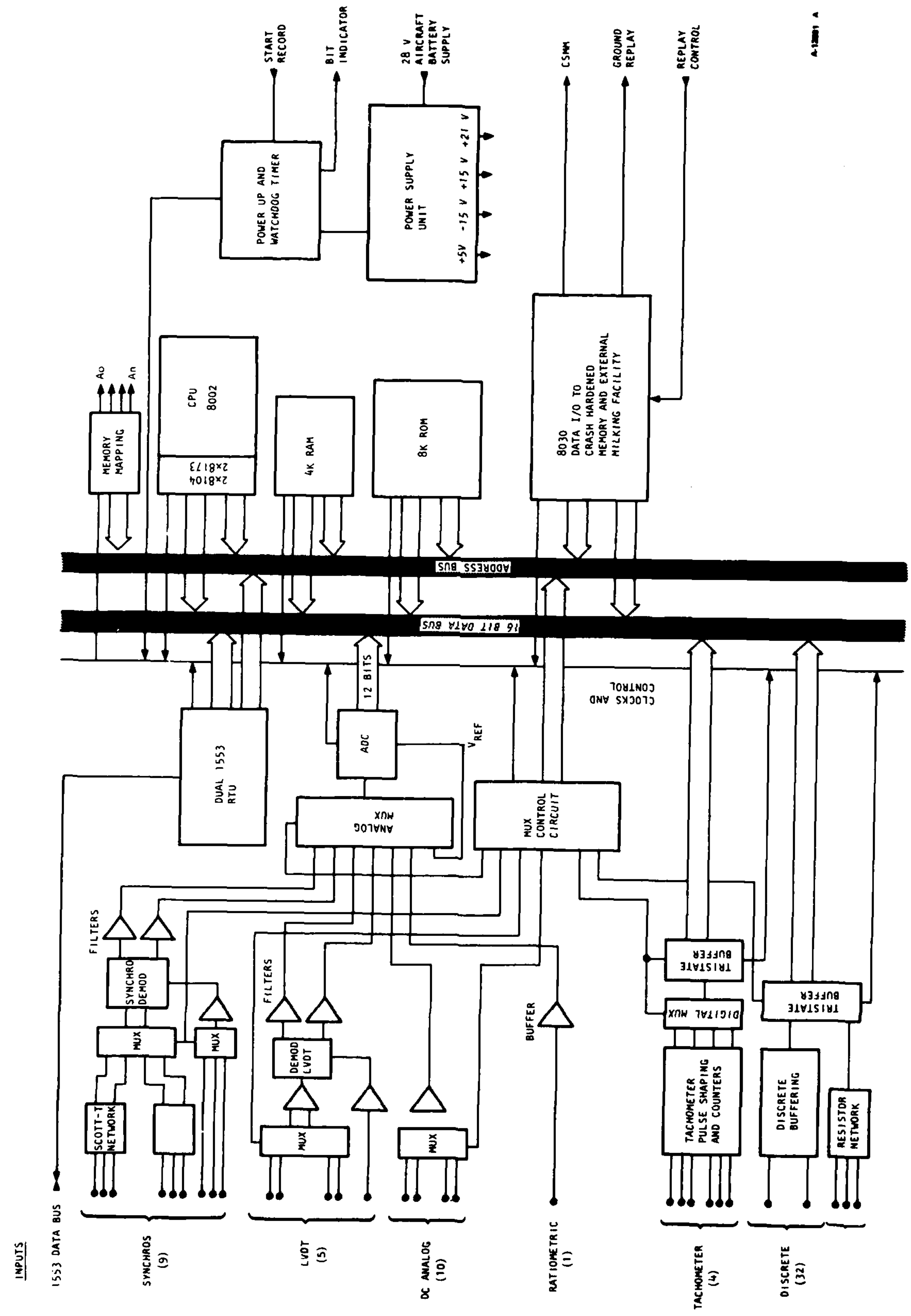


Figure 6-1. Configuration I System Block Diagram

(a) EMI as per MIL-STD-461A

(b) Current injection (back current)

(c) Impedance matching

In this application, particular reference will be made to MIL-E-5400, class A, general specification for airborne electronic equipment.

The three candidate aircraft have been studied, and the maximum number of any one type of analog parameter is shown in Table 6-1. A large amount of emphasis has been placed on making the system flexible and totally interchangeable between the candidate aircraft with a minimum amount of change to the hardware. This may increase the unit price by a small amount but the cost of having a dedicated system for each aircraft would be much higher, due to the spares and logistic support.

The differences between the three candidate aircraft and their various build standards are small enough to be included in one firmware module. The firmware module will be in the form of a look-up table. For each aircraft there would be a dedicated program block, each block labeled according to the aircraft in which the system is installed. The label would be identified by a code generated by hardwiring on the system connectors.

It is essential that the parameter data is correctly recognized and placed in the allocated address within the working store of the microprocessor (see Figure 6-2). The look-up table will be programmed into a programmable read only memory (PROM) and will contain the information relating to each parameter. This information will instruct the microprocessor which input channel a particular parameter is on, its sampling rate, accuracy, and allocated address in the working store. Once the data is correctly placed in the working store it is available for manipulations by the microprocessor.

TABLE 6-1

PARAMETER REQUIREMENTS FOR CONFIGURATION I

Parameter Type	Number
Synchro	9
LVDT (ac ratio)	5
Dc	10
Tachometer	4
Dc ratiometeric	1
Discrete	32
1553	10

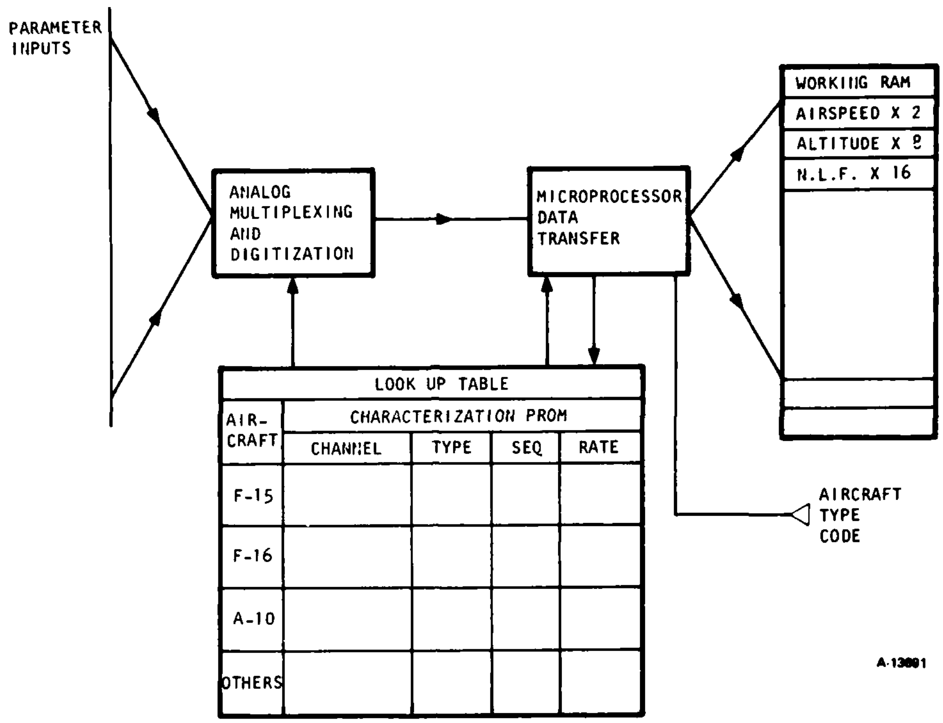


Figure 6-2. Control of Signal Input to Fixed Frame Store Format

The analog signals having various characteristics and the signal conditioning circuits are designed to produce a similar dc voltage range. This voltage is multiplexed using a CMOS analog multiplexer to the analog-to-digital converter. It is then converted to a 12-bit word in a two's complement notation. The discrete and digital parameters are multiplexed onto the microprocessor data bus using a tri-state buffer.

The serial data off the 1553 data bus is accessed and transferred onto the microprocessor data bus when required by the microprocessor program. As the microprocessor has a number of tasks to accomplish, the data compression algorithms being the most complex, a 16-bit microprocessor has been selected. This will allow some spare processing capability.

Once the data has been compressed and formatted into a recoverable form, it is transmitted to the CSMM via a serial interface port.

Built-in test is designed so that any failure within the system is indicated in the failed unit, data acquisition and processing unit, or memory module. It is assumed that the power for the CSFDR will be derived from the 28-vdc essential power bus. This would conform to MIL-STD-704D. The regulated supplies for the electronics within the CSFDR will be generated using a switching power supply.

Software Structure

The proposed software structure and timing relationships are shown in Figure 6-3. Interrupts can originate from three basic sources:

(a) The sampling frequency clock (16 per sec)

(b) The 1553 bus (to indicate data is available)

(c) The power up/power fail signal

Following an interrupt, the executive determines which real-time task is to be activated. On completion of the task, and if no other real-time tasks are pending, the executive activates the background (nonreal-time) scheduler, which in turn determines which background task should be continued or activated.

The real-time tasks will include control and input of the signals from the data acquisition circuits and 1553 data bus. The background tasks will perform the compression, data formatting, store control, and BIT. Although these tasks are not real-time critical in the same sense as the foreground tasks, they will need to be executed within a maximum time period in order to avoid data staleness.

Software Tasks

The main tasks to be performed by the software can be summarized as follows:

(a) Control of DAU hardware

  (1) A/D converter and multiplexer

  (2) 1553 remote terminal

(b) Data processing

  (1) Conditioning and conversion of input signals

  (2) Compression algorithms

(c) Data storage

  (1) Store formatting

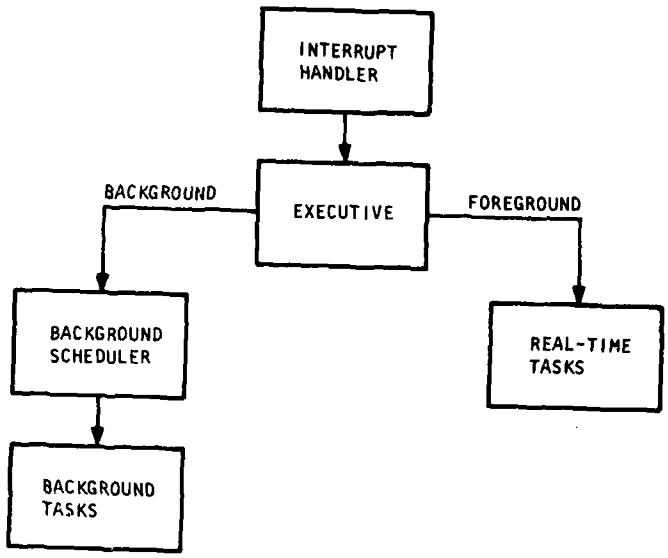
  (2) Store control

(d) Executive functions

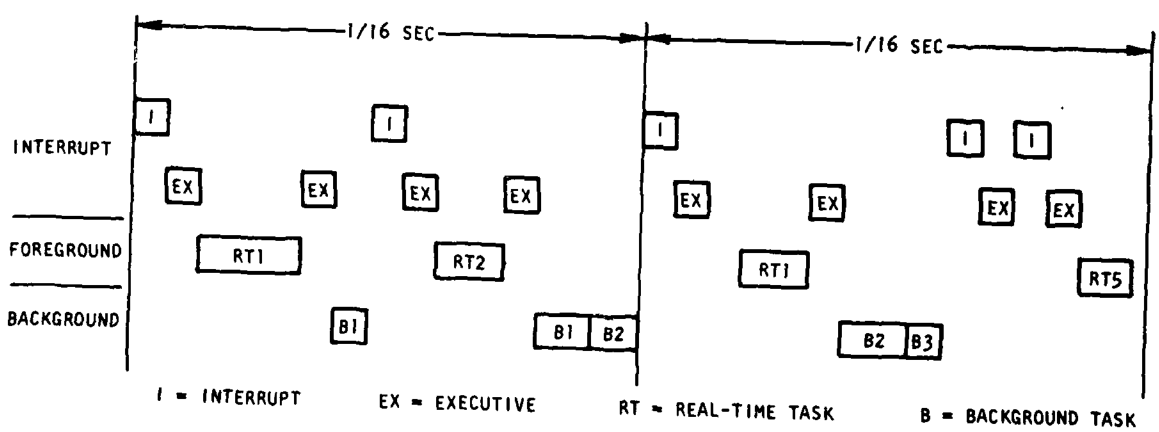
  (1) Power fail/restart and initialization

  (2) Timing and task scheduling

  (3) Auxiliary I/O (e.g., memory dump initialization)



(a) Software Structure



(b) Software Timing

A-12657

Figure 6-3. Proposed Software and Timing Relationships

(e) BIT

(1) Working storage and program memory checks

(2) Parameter range checks

(3) A/D and multiplexer checks

(4) Reference voltage checks

(5) CPU and I/O checks

(6) Watchdog and timer checks

Apart from the BIT that checks the memory and data acquisition circuitry, the additional sensors added for the CSFDR will be checked by verifying that correlated parameters follow each other. This would allow sensor malfunctions to be indicated although the onboard processing would not be powerful enough to detect small amounts of drift or loss of memory.

CONFIGURATION II

Configuration II is shown in Figure 6-4. The design restraints placed on this configuration by the Request for Quotation are "It shall utilize existing technology for data processing and recording capability which covers only the highest priority flight data requirements" and it "shall utilize technology which does not require additional development or testing before incorporation in the system."

The number of parameters that will be recorded in this configuration are shown in Table 6-2. The signal conditioning circuits that are used will be similar to the ones in configuration I.

The tasks that will be carried out by the microprocessor will be simplified due to the simpler data compression algorithms and the straightforward data format used. This can be carried out by an 8-bit microprocessor.

The BIT requirements are similar to those in configuration I.

CONFIGURATION III

Configuration III is shown in Figure 6-5. The requirement from the RFQ for this configuration calls for a system similar to configuration I, but showing the impact of the addition of a maintenance capability. The storage module for maintenance does not need crash protection.

The design of this configuration is similar to configuration I. To provide for maintenance data, the number of parameters and their appropriate signal conversion circuits have been increased (see Maintenance Recording, Section 3).

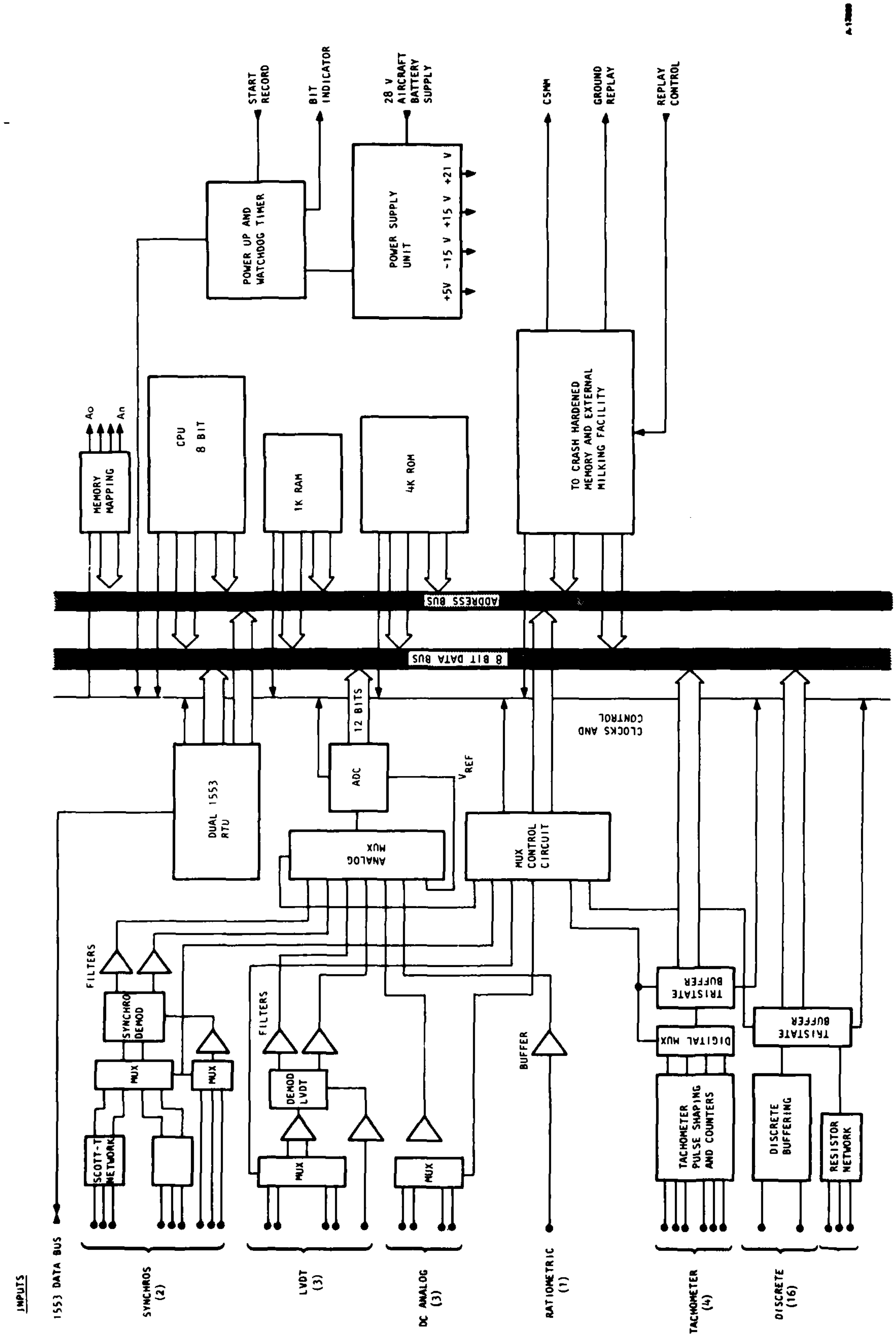


Figure 6-4. Configuration II System Block Diagram

TABLE 6-2

PARAMETER REQUIREMENTS FOR CONFIGURATION II

Parameter Type	Number
Synchro	2
LVDT (ac ratio)	3
Dc	3
Tachometer	4
Dc ratiometric	1
Discrete	16
1553 (dual bus)	1

The maintenance data requires a different type of data compression algorithm, so extra processor memory will be required. This memory will allow for the extra software and scratchpad requirements. Depending on the type of maintenance system implemented, a buffer store may be required. This will hold the data until it is instructed to dump onto the storage module. The storage module would need to be mounted in an accessible location in the aircraft, so that the data can be easily retrieved for maintenance purposes.

CSFDR Ground Replay Equipment

The ground replay equipment for the CSFDR will consist of three separate units to replay and assess the data collected during a flight. These units are the crash store milking equipment, the flight line analysis equipment, and the crash data replay system, and are described as follows.

Crash Store Milking Equipment

The crash store milking equipment will consist of a small portable unit that is carried to the aircraft by ground personnel. Replay is controlled via a front panel keypad, and this information is fed to a microprocessor in the replay unit that controls all operations. Data is read from the memory module and transmitted over a serial data link to the replay unit. It is then written to a cartridge recorder together with date, time, and aircraft number identification information entered via the keypad. This allows each cartridge to contain data from more than one flight, and it is envisaged that one cartridge will have enough capacity (approximately 10 MBit) for 3 to 4 flights (see Figure 6-6).

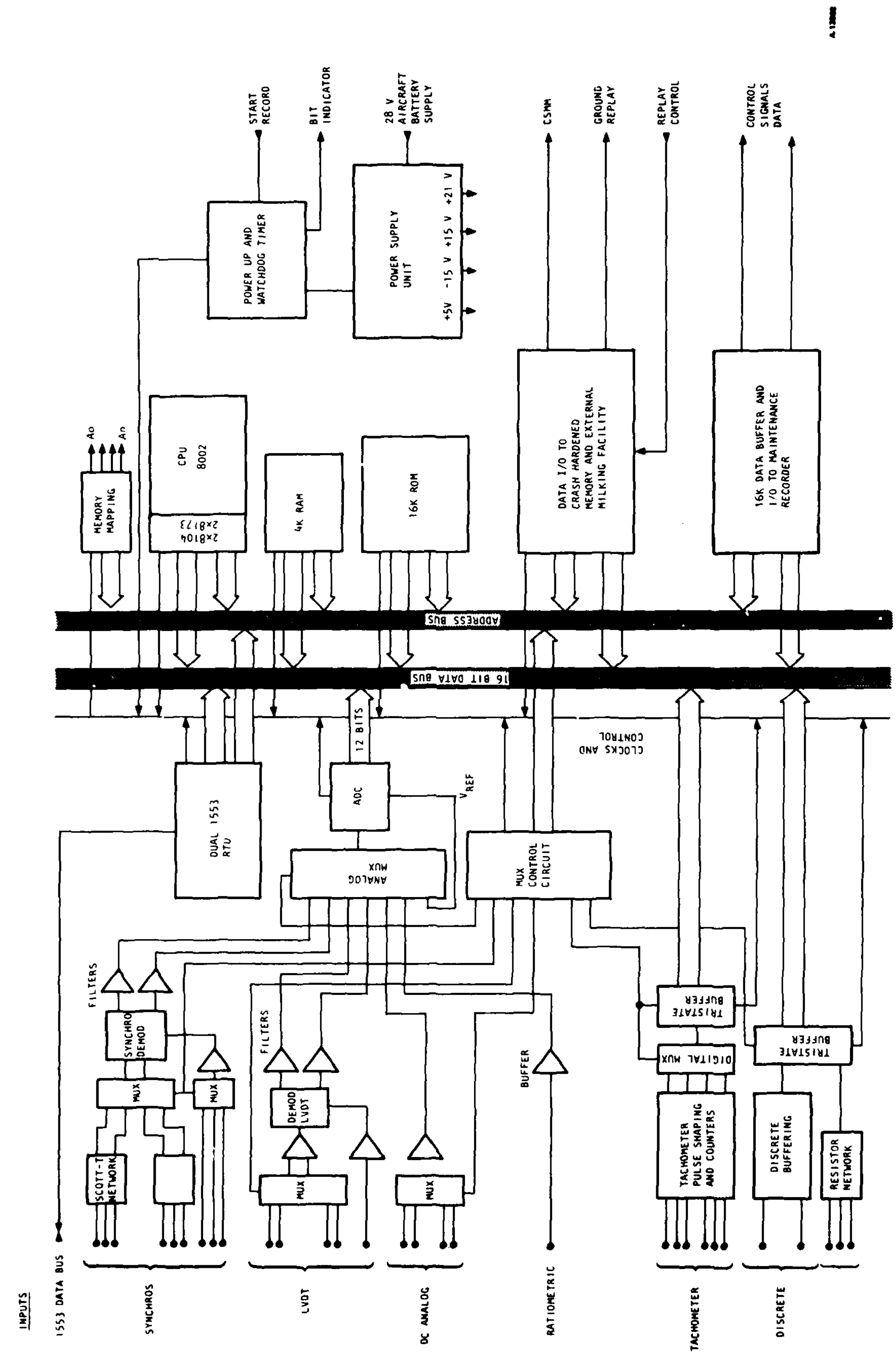


Figure 6-5. Configuration III System Block Diagram

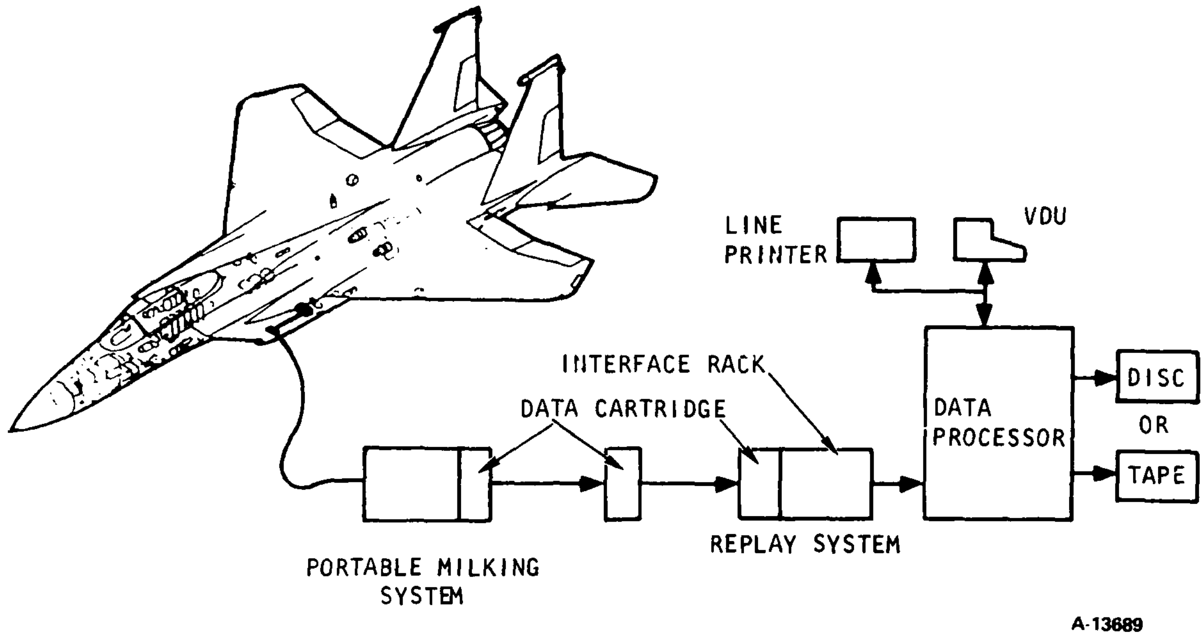


Figure 6-6. CSFDR Replay Equipment

The microprocessor will also perform a self-test at power on, and any status or error information will be indicated via front panel LED or LCD displays. If the chosen crash storage media is solid state, then an assessment of the data retention will be made every time the crash store is milked. This will be done by utilizing a soft erase or threshold voltage measurement technique, and if the test falls outside preset limits, then a fail condition will be indicated on the replay equipment control panel. The replay unit will be housed in a rugged, light, and sealed case, and will be constructed in accordance with MIL-T-21200.

Flight Line Analysis Equipment

This equipment will consist of an interface between the portable milking equipment and a PDP11/34 or similar minicomputer. The data analysis software will be stored on disc and act on data fed to it via a serial data link to the milking equipment. Operator control of the system will be via a video display unit (VDU), and results will be printed on a line printer or displayed on the VDU (see Figure 6-6).

Once the milking equipment has been connected to the data analysis computer, a keyboard command will initiate data extraction. The data is then written to magnetic disc or tape drive and stored together with the header identifying the date, time, and aircraft from which the data was collected. After all of the data has been read from the data cartridge and written onto tape or disc, the data analysis software will give the operator a choice of data processing procedures. The following options will be available:

> Output Device--The operator will be given a choice as to where the results of the analysis computations are to be output. Three options will be available: VDU, line printer, or stored on disc for later printing or access.
>
> Parameters of Interest--The operator will be given a choice as to whether all the parameters or only a subset of the parameters are analyzed. The audio channel will be constantly monitored and available via a self-contained loudspeaker or external headphones.
>
> Output Format--The operator will be given a choice as to the format of the output data. Depending on the parameters and the sort of information that is required from the data, the operator may want to select either graphical or tabulated results. The timescale of the analysis window will also be variable from a few minutes of the flight to the last 30 min.

The analysis system will be housed in a free-standing case and will interface to the minicomputer using a parallel interface card.

Crash Data Replay System

The crash data replay system will be capable of replaying and analyzing data from the CSFDR after a crash or incident. To perform this task, the CSFDR is removed from the aircraft and plugged into the data analysis computer system described in the preceeding section. Data extraction is initiated with a keyboard command, and data is then read from the CSFDR and written to an IBM format, 9-track, 1600-BPI, 0.5-in. tape system (see Figure 6-7).

For quick-look assessment, this data can then be used in the same way as the data from the portable replay machine. Alternatively, the IBM-format tape can be taken to one of the IBM 370 computers that are used by the Air Force for crash investigation and a full analysis performed.

Maintenance Support Equipment

The expected high reliability of the CSFDR airborne components leads to a maintenance philosophy in which all actual unit repair and retest is accomplished at intermediate or depot-level maintenance facilities. Only spare units are stored at organizational level.

At intermediate and depot level, maintenance is supported by spare modules and special test equipment. Modules are interchangeable without recalibration and do not require special tools for replacement. Established module costs are included in the life-cycle cost analysis.

The special test equipment that is projected for CSFDR support is to allow full exercising of all unit inputs and display of all unit outputs. No interconnection to standardized ATE is assumed. All analog input channels may be

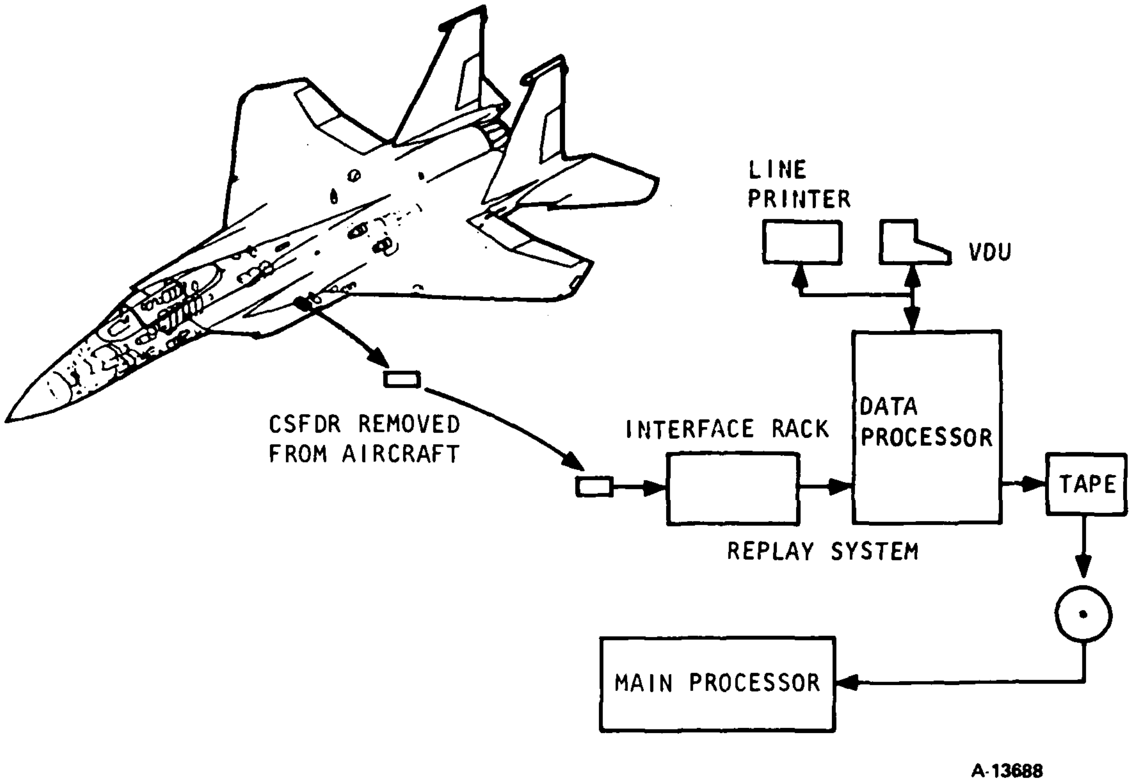


Figure 6-7. Crash Data Replay System

adjusted to any point in their ranges. The MIL-STD-1553 data bus may be exercised through a range of data values and various fault modes. In addition, special test connections on both units will permit evaluation of required internal test points, such as power supply voltages. The panel will be sufficient to allow a complete retest of a repaired unit prior to return to service or stock.

SECTION 7

COST EFFECTIVENESS

LIFE-CYCLE COST

Two models have been used to study the life-cycle costs (LCC) of the proposed CSFDR systems: (1) the simple model detailed below, which indicates the parameters and sensitivities involved, and (2) the LCC-2A model, a more comprehensive LCC model developed by the USAF.

Simple Model

The total life-cycle cost will include both the system acquisition costs and the support costs incurred throughout the system lifetime. For simplicity the model will consider the data acquisition unit (DAU) and the memory module (MM) as two separate spares, which have to be returned to intermediate level (IL) for repair. The further breakdown of these line replaceable units (LRU's) into shop replaceable units (SRU's) will not be considered in the simple model, the support cost being calculated for one IL support center. Total support cost equals initial spares cost plus follow-on spares cost, repair cost, manpower cost, and test equipment support cost.

Initial Spares Cost

The initial spares required will depend on the total aircraft flying hours, the repair time, the mean time between failures of the DAU and MM, the number of condemned units (lost on aircraft or unserviceable) and the initial support period.

Let: N_H = total aircraft flying hours per base per month

R_T = repair rate, base to IL and return to base in months

P_I = initial support period in months

F_D = DAU condemnation rate (per month)

F_M = MM condemnation rate (per month)

M_D = DAU MTBF (hours)

M_M = MM MTBF (hours)

For the DAU, the number of initial spares will be given by

$$N_{ID} = \left[\frac{N_H * R_T * P_I}{M_O} + F_D * P_I\right]$$

and for the MM the number of initial spares will be given by

$$N_{IM} = \left[\frac{N_H * R_T * P_I}{M_M} + F_M * P_I\right]$$

However, in order to ensure that no spare is unrepaired at the base due to back-orders, a safety stock is required. Assuming a 96 percent safety stock level and that the spares demand follows a Poisson distribution, the total cost of the initial spares is given by

$$\text{Initial spares cost} = \left(N_{ID} + \sqrt{3N_{ID}}\right) * C_D + \left(N_{IM} + \sqrt{3N_{IM}}\right) * C_M$$

where C_D = cost of DAU in dollars

C_M = cost of MM in dollars

Graph 1 illustrates the initial spares cost for single LRU's costing \$8000 (DAU) and \$4000 (MM) against their mean time between failure (MTBF) for one IL support center.

Follow-on Spares

For the follow-on period, no safety stock is required in addition to the initial spares, the only additions to the repair cycle being the spares to replace the condemned stock (the effect of this stock being reduced throughout the life-cycle due to the effectiveness of the CSFDR in aircraft saves will not be considered).

Let P_F = follow-on support period (months)

then $\text{Follow-on spares cost} = N_H * P_F * \left[F_D * C_D + F_M * C_M\right]$

Repair Cost

If it is assumed that the repair cost averages 20 percent of the new cost

$$\text{Repair cost} = 0.2 * N_H * (P_I + P_F) * \left[\frac{C_D}{M_D} + \frac{C_M}{M_M}\right]$$

Graph 2 shows the repair costs of the DAU and MM for the total support period of 20 yr against MTBF, for costs of \$8000 (DAU) and \$4000 (MM).

Manpower Cost

If a manhour rate in dollars of C_H per flight hour is assumed

$$\text{Manpower cost} = N_H * (P_I + P_F) * C_H$$

Test Equipment Support

The cost of the test equipment support is assumed to be 1 percent of the test equipment cost, C_T per year

$$\text{Total equipment support cost} = 0.01 * (P_I + P_F) * C_T$$

Total Cost of Configuration I

As well as simplifying the repair cycle structure other factors such as development costs, expense spares, training costs, shipping costs, data management costs, and warranty agreements have been ignored for this simplified model. If we assume the following parameter values:

Number of aircraft (A-10, F-15, F-16)	=	3150
Number of bases	=	68
Number of intermediate levels (IL)	=	10
Repair turnaround time (R_T)	=	2 months
Flying time per month	=	25 hours
Condemnation rates	=	0
Initial support period (P_I)	=	12 months
Follow-on period	=	228 months
DAU MTBF (M_D)	=	12,000 hours
MM MTBF (M_M)	=	8000 hours
DAU cost (C_D)	=	$8000
MM cost (C_M)	=	$4000
Replay unit (1 at each IL) cost	=	$17,000
Milking unit (1 at each base) cost	=	$12,000
DAU and MM test set	=	$50,000
Manpower rate per flight hour (at each IL)	=	$0.25
Installation cost per aircraft	=	$8000

For a fleet-wide fit the following values are obtained for the acquisition and support costs:

Item	Cost, $M
Prime equipment cost	37.8
Test equipment and replay cost	1.5
Installation cost	24.0
Initial spares cost	3.2
Follow-on spares cost	0
Repair cost	4.4
Manpower cost	4.7
Test equipment and replay support cost	3.0
Total 20 yr cost of ownership	78.6

Although the total life-cycle cost is determined mainly by the prime equipment and installation costs, the LCC is also sensitive to the MTBF's of the DAU and MM. For example, if the MTBF's are half those estimated for the two units the LCC is increased to $82.7 M. If they are halved again the LCC is further increased to $99.7 M (see Figure 7-1). It would therefore appear that if the proposed MTBF's can be validated, effort should be directed towards decreasing the prime equipment and installation costs (see Figure 7-2). The development costs have not been included in the model, and it assumed they are a small proportion of the total LCC.

Other Configuration Costs

The costs for configurations II and III will not be separately estimated. However, it is clear from the Total Cost of Configuration I (Section 7) that the cost will be dictated by the equipment and installation costs providing the equipment MTBF is above 3000 hr.

COST BENEFIT

Technical report NY1245 summarizes the USAF Norton incident reports for the period 1976 to 1980 (4-1/2 yr) on fighter, trainer, and attack aircraft. From these results the following table may be compiled indicating the average number of damaged aircraft, lost aircraft, and loss of life per year.

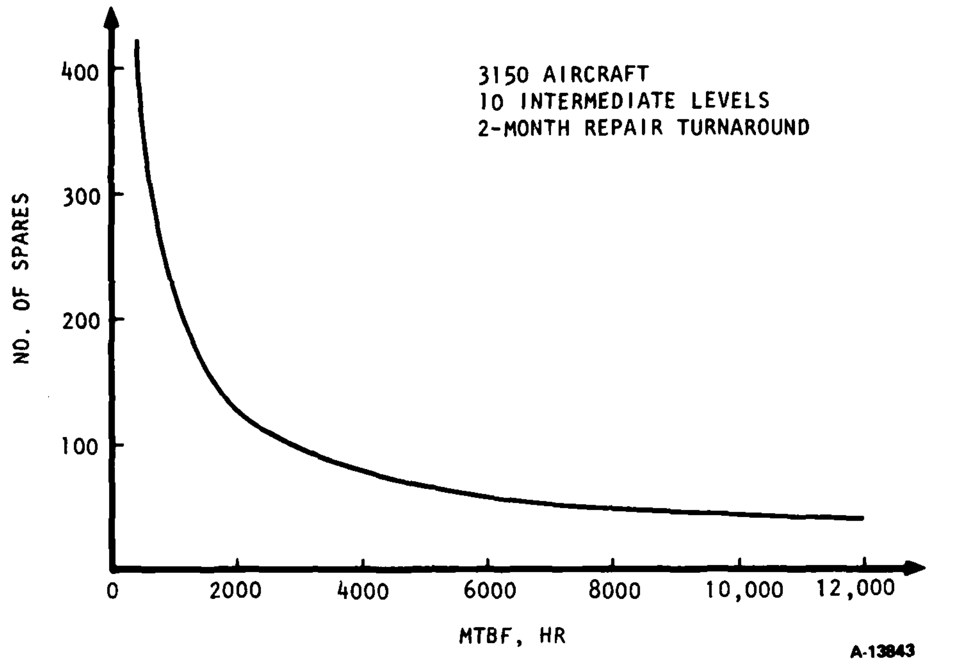


Figure 7-1. MTBF Total Spares Holding at 10 Intermediate Levels

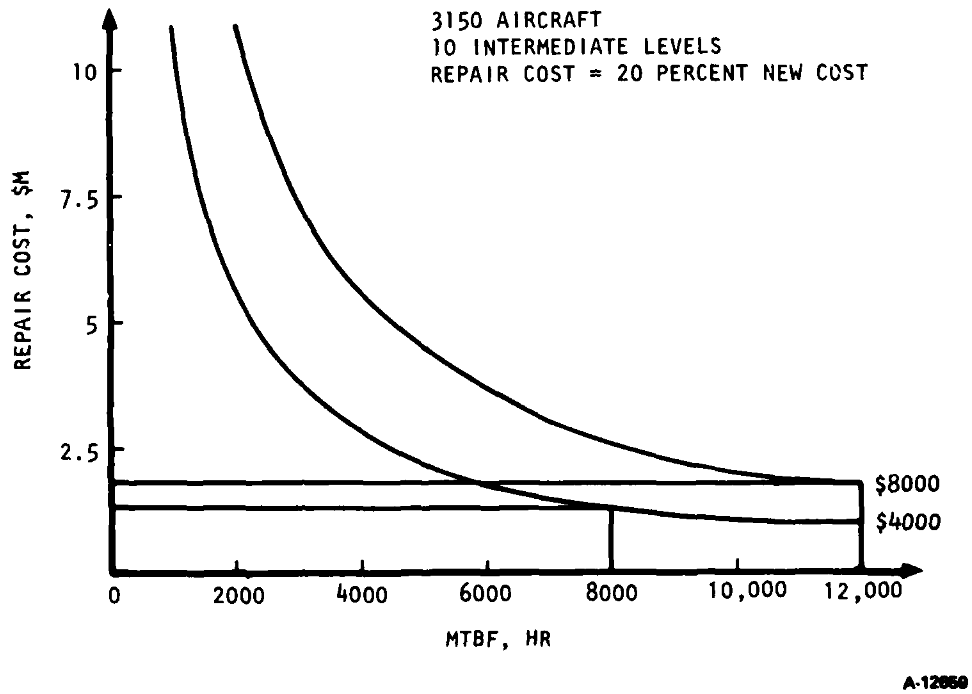


Figure 7-2. MTBF Repair Cost for the Two LRU Costs

	Aircraft Lost	Aircraft Damaged	Personnel Lost	Aircraft Lost at Sea	Aircraft Lost Over Land
Total incidents	70	112	40	4	66
Incidents with inconclusive reports	37	16	21	3	34

Total aircraft from which sample was taken is approximately 5000

For the analysis the following average data were assumed:

New aircraft cost = \$15 M

Average damage cost = 20 percent new aircraft cost

Sea recovery cost = \$1/2 M

Land recovery cost = \$100,000

Loss of life cost = \$1 M

It is difficult to quantify the effectiveness of the CSFDR in changing incidents associated with inconclusive findings into conclusive reports that lead to positive actions resulting in aircraft saves. However, it is considered reasonable that the CSFDR will lead to a minimum of 1 in 10 aircraft saves averaged over the whole life cycle (i.e., 10 percent composite effectiveness).

From the analysis of 818 U.S. Air Force accidents, 53 percent were inconclusive as to the cause where the aircraft was a total loss (see Appendix M).

In addition, a 20-yr life-cycle leading to a 19-yr benefit-cycle is assumed. Using these figures the total cost of aircraft incidents per year is:

Current cost = Damage cost + overland total loss costs + at sea total loss costs + personnel loss costs

Current cost, \$M = damage (112 x 0.2 x 15) + land loss (66 x 15.1) + sea loss (4 x 15.5) + personnel loss (40 x 1)

giving a total cost per year of \$1435 million dollars. Since the expected numbers of A-10, F-15, and F-16 aircraft is less than the statistical sample size, this figure will be factored by 0.6. If 100 percent effectiveness in saving losses with inconclusive findings is assumed, the formula above gives

100 percent effectiveness cost saving per year, \$M = damage (16 x 0.2 x 15) + land loss (34 x 15.1) + sea loss (3 x 15.5) + personnel loss (21 x 1)

giving a total cost saving per year of $628 million. Again this will be factored by 0.6 in order to obtain the projected figure for 100 percent effectiveness of the CSFDR in airplane saves.

Table 7-1 shows the total cost savings for the minimum (10 percent), expected (20 percent), and maximum (50 percent) estimated composite effectiveness of the CSFDR system in reducing aircraft incidents.

TABLE 7-1

COST SAVINGS

Composite Effectiveness, percent	Average Savings per year, $M	Total Savings Over Life Cycle, $M
10	38	722
20	76	1444
30	114	2166
40	152	2888
50	190	3610

COST BENEFIT CONCLUSION

For a composite effectiveness of 10 percent (the absolute expected minimum) and an LCC of $78.6 million, a cost benefit is achieved after about 2 years of installation, the final benefit being in the region of 800 percent. Since the aircraft loss costs and the CSFDR effectiveness are conservative figures, it is clear there is considerable benefit to be gained from fitting the crash recorder system.

LIFE-CYCLE COST ANALYSIS--LCC-2A MODEL

The object of this study is to estimate the total cost of ownership or life-cycle cost of the proposed flight recorder system.

The preliminary undiscounted life-cycle cost estimate using the LCC-2A computer model is $65.9 million. This estimate includes the cost of one spare each of the DAPU and the memory module unit at each base (68 bases) and the cost of one spare of each SRU at each of the intermediate level bases (11 intermediate bases).

The prime equipment costs used in the LCC analysis assume a memory module cost of $4000. The actual memory cost will depend on whether it is decided to include audio recording, the point of introduction, and the memory type to be utilized. Figure 7-3 gives an indication of the comparative costs for each potential memory type against year of introduction.

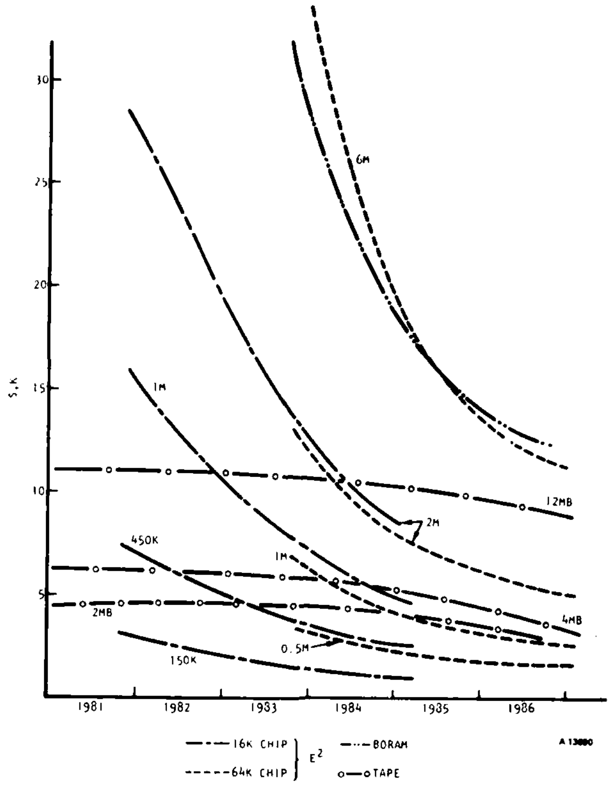


Figure 7-3. Approximate Costing Storage Availability Prediction

Preliminary sensitivity analyses using the LCC-2A model indicated that doubling the system operating hours per month increased the total life-cycle cost by 0.8 percent; however, doubling the cost per system installation increased the total life-cycle cost by 38 percent. The plots of those parameters versus total life-cycle cost (undiscounted) are shown in Figures 7-4 and 7-5.

Model Description

The life-cycle cost computer model used in the determination of the life-cycle cost of the flight recorder is the LCC-2A model used at Wright Patterson. This model requires as input standard cost factors, logistic factors, hardware definition, support equipment, and contractor data. It calculates the following cost categories:

(a) Acquisition cost

(1) Initial training

(2) Technical data acquisition

(3) Initial item management

(4) Initial data management

(5) Hardware

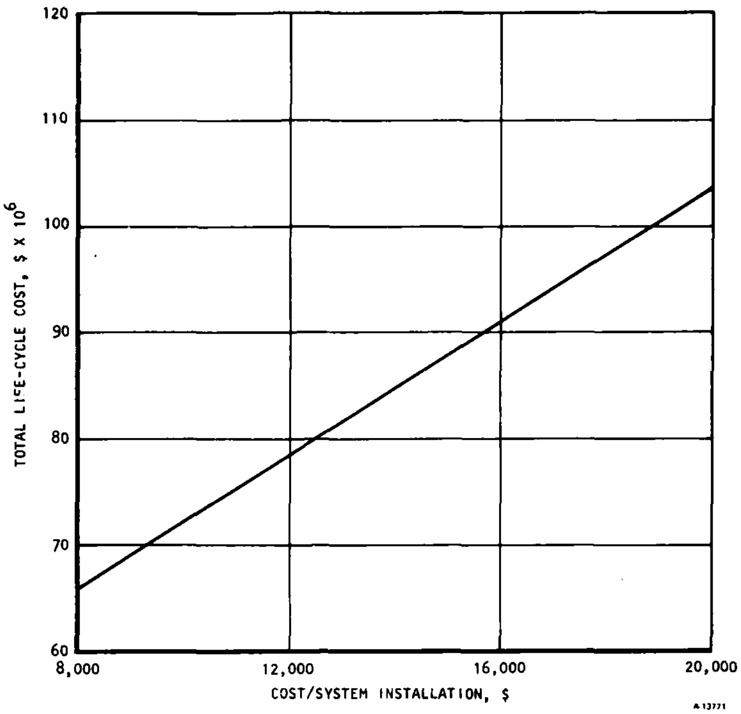


Figure 7-4. Cost Per System Installation Vs Total Life-Cycle Cost

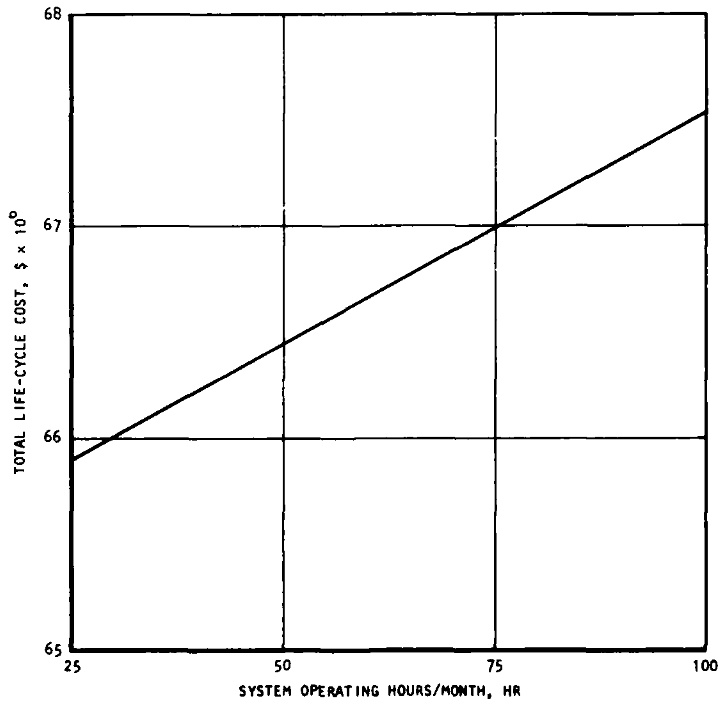


Figure 7-5. System Operating Hours Per Month Vs Total Life-Cycle Cost

(6) Support equipment

(7) Initial spares

(8) Installation

(9) Warranty

(b) Operation and maintenance cost

(1) Flight line maintenance

(2) Intermediate level maintenance

(3) Depot maintenance

(4) Recurring item management

(5) Recurring data management

(6) Packaging and shipping

(7) Support equipment maintenance

It provides eight output options, which are as follows:

(a) Input data

(b) Support equipment requirements

(c) Spares requirements (detailed)

(d) Spares requirements (unit totals)

(e) Manpower requirements

(f) Total cost summary (by category)

(g) Total cost summary (by year)

(h) Sensitivity analysis results

The LCC-2A model is used for tradeoff and cost benefit analyses of avionics systems and is now being used by most aerospace companies to respond to request for proposals.

A glossary of symbols used in this model is shown in Exhibit 7A.

Computer Runs

The outputs of the computer runs are given in Exhibits 7B, 7C, and 7D. Exhibit 7B is the output for the basic run. Exhibit 7C is the output of the sensitivity analysis done on the cost per system installation. Exhibit 7D is the output of the sensitivity analysis done on the system operating hours per month.

In these outputs, the computed spares at the bases for the LRU's and the SRU's are zero because of high mean time between failures (MTBF) and a fast turnaround cycle. In the calculation of the total life-cycle cost estimate, the cost of the 68 bases and the cost of one spare of each of the SRU's at each of the 11 intermediate levels were included. This cost, which was determined separately, is $948,000.

APPENDIXES

Appendixes A through M are included with this report. Although the appendixes are not all individually referenced within the body of the report, the information contained within each of the appendixes was taken into account during the formulation of the study's conclusions and recommendations.

EXHIBIT 7A

GLOSSARY OF SYMBOLS

EXHIBIT 7A

GLOSSARY OF SYMBOLS

ACS - Acquisition cost in dollars per system

AO_e - LRU availability objective (the steady-state probability that an LRU is not in an unreparable state at base level due to a backorder on the SRU spare supply)

AO_s - System availability objective (the steady-state probability that an aircraft is not in NORS (Not Operationally Ready due to Supply) status due to an LRU backorder

AO1 - Spares objective (system)

AO2 - Spares objective (shop)

BDSA - Average shipping time in hours from base to depot

BDSC - Average shipping time in hours to depot from CONUS bases

BDSO - Average shipping time in hours to depot from overseas bases

BTC - Base training cost in dollars

C_k - Total cost in dollars incurred by the Government in year k

C_{ik} - Value in dollars of LCC element i incurred in year k

CDMC - Contractor depot repair cycle time in hours

COM_j - Annual cost to operate and maintain a set of support equipment item j, expressed as a fraction of the acquistion cost

$COND_i$ - Expected fraction of unit i failures resulting in unit condemnation

CPS_i - The average shipping cost in dollars per shipment of unit i

CRSC - Resupply time in hours from contractor facility to CONUS bases

CRSO - Resupply time in hours from contractor facility to overseas bases

CRU_i - Cost in dollars per unit for spare of unit i

CSE_j - Unit cost in dollars for support equipment line item j

D_i - Demand rate in demands per hour of unit i on the depot spare supply

D_{im} - Demand rate in demands per hour for spares of unit i at base m

DCB - Base repair technical orders cost in dollars

DCD - Depot repair technical orders cost in dollars

DCO - Operation technical orders cost in dollars

DF - Annual discount factor applied to future costs

DMC - Depot repair cycle time in hours for units which can be repaired by removal and replacement operations (RTS type repairs)

DRC - Depot repair cycle time in hours for units which require actions more complex than removal and replacement operations (NRTS repairs)

DSSF - Depot stock safety factor in standard deviations

DTC - Depot training cost in dollars

EBD_{im} - Expected delay in hours for repair of LRU i at base m due to stockout of spare SRU

EBD_{ijm} - Expected delay in hours for repair of LRU i at base m due to stockout of SRU j

EBO_{em} - Expected LRU backorders at base m

EBO_{sm} - Expected SRU backorders at base m

EDO_i - Expected delay in hours in RTS repair of LRU i due to stockout of spare SRUs

EDO_{ij} - Expected depot delay in hours in RTS repair of LRU i due to stockout of SRU j

ENR_{ik} - Expected number of removals of unit i in year k

ESO_i - Expected resupply time delay in hours due to depot stockout of unit i

FVS_i - Labor standard in hours for failure verification of unit i

G_k - Ratio of the projected system Mean Time Between Failures (MTBF) in year k to the initial MTBF

G_{km} - Ratio of the projected system MTBF in month m of year k to the initial system MTBF

G* - Ratio of the projected system MTBF at the time of full installation to the initial system MTBF

I_e - Set of indices pertaining to LRUs

I_s - Set of indices pertaining to SRUs

ISITE - Number of I level sites at which aircraft using the system are deployed

ISP - Initial support period (years)

$ISYS_m$ - Number of I level systems to be installed at site m

i* - Index of the unit which provides the greatest reduction in expected backorders in a particular iteration of the base level spares determination algorithm

J_b - Set of indices pertaining to line items of support equipment required at base level

J_d - Set of indices pertaining to line items of support equipment required at depot level

J_i - Set of indices pertaining to SRUs contained in LRU i

LR_i - Maintenance level of repair (initial support period) for unit i: $LR_i = 0$ (flight line); = 1 (base); = 2 (depot)

$LR2_i$ - Maintenance level of repair (final support period) for unit i: $LR2_i = 0$ (flight line); = 1 (base); = 2 (depot)

$LREM_i$ - Maintenance level of removal for unit i: $LREM_i = 0$ (flight line); = 1 (base); = 2 (depot)

LSER - Support Equipment required for repair of item

LV_i - Maintenance level of failure verification (initial support period) for unit i: $LV_i = 0$ (flight line); = 1 (base); = 2 (depot)

$LV2_i$ - Maintenance level of failure verification (final support period) for unit i: $LV2_i = 0$ (flight line); = 1 (base); = 2 (depot)

$MTBF_i$ - Mean Time Between Failures of unit i in hours

n_j - Number of sets of support equipment item j required at depot

n_{im} - Current spares level of unit i at base m in a particular iteration of the base level spares determination algorithm

NAC_k - Number of systems installed in year k

NBASE - Total number of bases at which aircraft using the system are deployed

NBC	-	Number of bases - CONUS
NBO	-	Number of bases - overseas
NCS_i	-	Number of condemnation spares of unit i
$NCUM_{km}$	-	Cumulative number of systems installed by month m of year k
NDS	-	Number of depot work shifts per day
NI	-	Number of new items (no Federal Stock Number assigned) in the proposed design which must be stocked by the Government to support system maintenance
NIC	-	Number of I level sites CONUS
NIO	-	Number of I level sites overseas
NIS	-	Number of I level work shifts
NPB	-	Number of pages of base repair technical orders
NPD	-	Number of pages of depot repair technical orders
NPO	-	Number of pages of operation technical orders
NQ_i	-	Quantity of unit i required per system
$NREQ_{jk}$	-	Number of sets of support equipment item j required in year k
NRS_i	-	Total number of initial spares required for unit i
$NRSB_{im}$	-	Number of spares of unit i required at base m
$NRSD_i$	-	Number of spares of unit i required at the depot
NRU	-	Number of replaceable units in the system hardware configuration (counting the system itself)
$NRTS_i$	-	Expected fraction of failures of unit i that are reparable only at depot
NS_c	-	Total number of systems to be installed on aircraft at CONUS bases
NS_o	-	Total number of systems to be installed at overseas bases
NSE	-	Number of unique line items of support equipment
$NSYS_m$	-	Total number of systems to be installed at base m

NTOT - Total number of systems to be installed

NY - Operational life of the system in years

OH - Average operating hours per month per installed system

$RBHPM_{j,m}$ - The expected hours per month that support equipment item j is required at base m

$RHPM_j$ - Expected hours per month that support equipment item j is required at depot

RLS_1 - Average labor in manhours per in-place system repair

RLS_i - Average labor in manhours per NRTS repair of unit i

RMS_1 - Average materials cost in dollars per in-place system repair

RMS_i - Average materials cost in dollars per NRTS repair of unit i

RRS_i - Average labor in manhours required to isolate a failure to unit i, remove the unit, replace it with a spare, and verify the corrective action

RST_m - Resupply time in hours to base m

RSTC - Resupply time in hours between the depot and CONUS bases

RSTO - Resupply time in hours between the depot and overseas bases

RTS_1 - Expected fraction of system failures that are reparable in-place

RTS_i - Expected fraction of failures of unit i that are reparable by removal and replacement operations

SBMC - Consumable materials consumption rate in dollars per manhour at base level

SBR - Standard base labor rate in dollars per manhour

SDC2 - Consumable materials consumption rate in dollars per manhour at depot level for final support period

SDM - Standard data management cost in dollars per page per year

SDMC - Consumable materials consumption rate in dollars per manhour at depot level for initial support period

SDR - Standard depot labor rate in dollars per manhour for initial support period

SDR2 - Standard depot labor rate in dollars per manhour for final support period

SID - Standard cost in dollars per copy per page for reproduction and distribution of technical data

SIE - Standard cost in dollars per item for entering a new item into the Government supply system

SIM - Standard inventory management cost in dollars per year

SIN - Installation cost in dollars per system

SPSC - Standard cost in dollars per pound for packaging and shipping units between the depot and CONUS bases

SPSO - Standard cost in dollars per pound for packaging and shipping units between the depot and overseas bases

T_i - Depot stock replenishment time in hours for unit i

T_{im} - Stock replenishment time in hours for unit i at base m

TAT - Base turnaround time in hours

$TOTCOS_{pv}$-Total life cycle cost for the system in present value dollars

$TOTCOS_u$- Total life cycle cost for the system in undiscounted dollars

UFP_i - Expected fraction of removals of unit i that will be unverified failures (RTOKs)

$USER_{ij}$ - Support equipment item j usage time in hours for repair of unit i

$USEV_{ij}$ - Support equipment item j usage time in hours for verification of unit i

W_i - Weight in pounds for unit i

WHPM - Working hours per month at the depot

WHPS - Working hours per month at the site

WP - Warranty period in years

WPR - Price of the warranty in dollars

im - A variable in the base level spares determination algorithm denoting the reduction in expected backorders at base m achieved by increasing the current spares level of unit i at base m by one

o (Statement) - A variable whose value is 1 if the statement is true and 0 otherwise

EXHIBIT 7B

BASE RUN

LIFE CYCLE COST ANALYSIS PROGRAM

00081079

STANDARD ELEMENTS FILE

PARAMETER	VALUE
SIE: ITEM ENTRY COST/NEW ITEM	1200.00
SBR: BASE LABOR RATE/HOUR	16.42
SDR: DEPOT LABOR RATE/HOUR	29.43
SDR2: DEPOT LABOR RATE/HOUR,#2	29.43
SPSC: PACKAGING & SHIPPING COST/LB. - CONUS	0.58
SPSO: PACKAGING & SHIPPING COST/LB. - OVERSEAS	0.72
SID: INITIAL DATA MGT. COST/COPY/PAGE	0.0110
SIM: ITEM MGT. COST/ITEM/YEAR	150.00
SDM: DATA MGT. COST/PAGE/YEAR	97.55
SBMC: BASE MATERIAL CONSUMPTION RATE	0.0
SDMC: DEPOT MATERIAL CONSUMPTION RATE	8.84
SDC2: DEPOT MATERIAL CONSUMPTION RATE,#2	8.84
DF: DISCOUNT FACTOR	0.10

LOGISTIC FACTORS FILE

PARAMETER	VALUE
NY: OPERATIONAL LIFE OF SYSTEM (YEARS)	20
NBC: NUMBER OF BASES - CONUS	62
NIC: NUMBER OF I-LEVEL SITES - CONUS	10
NBO: NUMBER OF BASES - OVERSEAS	6
NIO: NUMBER OF I LEVEL SITES - OVERSEAS	1
NSC: NUMBER OF SYSTEMS - CONUS	2874
NSO: NUMBER OF SYSTEMS - OVERSEAS	276

NUMBER OF SYSTEMS AT EACH BASE - CONUS

NUMBER OF BASES	SYSTEMS AT BASE
2	17
40	41
20	60

NUMBER OF SYSTEMS AT EACH I-LEVEL SITE - CONUS

NUMBER OF SITES	SYSTEMS AT SITE
6	287
4	288

NUMBER OF SYSTEMS AT EACH BASE - OVERSEAS

NUMBER OF BASES	SYSTEMS AT BASE
6	46

NUMBER OF SYSTEMS AT EACH I-LEVEL SITE - OVERSEAS

NUMBER OF SITES	SYSTEMS AT SITE
1	276

SIN:	COST/SYSTEM INSTALLATION	8000.00
OH:	SYSTEM OPERATING HOURS/MONTH	25.0
NDS:	NUMBER OF DEPOT WORK SHIFTS	2
NIS:	NUMBER OF I LEVEL WORK SHIFTS	2
RSTC:	BASE RESUPPLY TIME - CONUS (HOURS)	396.
RSTO:	BASE RESUPPLY TIME - OVERSEAS (HOURS)	384.
DMC:	DEPOT REPLACEMENT CYCLE TIME (HOURS)	612.
DRC:	DEPOT REPAIR CYCLE TIME (HOURS)	1224.
BDSC:	SHIPPING TIME TO DEPOT - CONUS (HOURS)	144.
BDSO:	SHIPPING TIME TO DEPOT - OVERSEAS (HOURS)	252.
TAT:	BASE TURNAROUND TIME (HOURS)	96.
WP:	SYSTEM WARRANTY PERIOD (YEARS)	1
ISP:	INITIAL SUPPORT PERIOD (YEARS)	1
AO1:	SPARES OBJECTIVE (SYSTEM)	0.990
AO2:	SPARES OBJECTIVE (SHOP)	0.990
DSSF:	DEPOT STOCK SAFETY FACTOR	1.65

ACTIVATION SCHEDULE

	MONTH											
YEAR	1	2	3	4	5	6	7	8	9	10	11	12
1	52	52	52	52	52	52	52	52	52	52	52	52
2	52	52	52	52	52	52	52	52	52	52	52	52
3	52	52	52	52	52	52	53	53	53	53	53	53
4	53	53	53	53	53	53	53	53	53	53	53	53
5	53	53	53	53	53	53	53	53	53	53	53	53

HARDWARE DEFINITION FILE

NUMBER OF REPLACEABLE UNITS = 14

LN	IN	NOMENCLATURE	NQ	CRU	MTBF	UFP	W	FVS	RLS	RRS
1	1	SYSTEM	1	12,000.	4,847.	0.000	17.5	0.0	0.0	0.0
2	2	DATA ACQUISITION	1	8,000.	12,299.	0.020	11.5	0.0	0.0	1.0
3	3	MOTHERBOARD ASSY	1	700.	10,000,000.	0.050	0.8	0.3	1.7	0.0
4	3	SIGNAL CONDITIONER	1	1,000.	73,899.	0.050	0.4	0.3	1.7	0.0
5	3	SIGNAL CONDITIONER	1	1,000.	65,902.	0.050	0.4	0.3	1.7	0.0
6	3	RTU 1553	1	1,400.	88,028.	0.050	0.4	0.3	1.7	0.0
7	3	CPU AND MEMORY	1	1,400.	68,078.	0.050	0.4	0.3	1.7	0.0
8	3	ADC CONTROL AND IO	1	1,000.	72,674.	0.050	0.3	0.3	1.7	0.0

9	3 CHASSIS PSU DA	1	1,500.	78,247.	0.050	9.0	0.3	1.7	0.0
10	2 MEMORY MODULE	1	4,000.	8,000.	0.020	6.0	0.0	0.0	1.0
11	3 MEMORY STORAGE	1	1,500.	12,195.	0.050	0.5	0.3	1.7	0.0
12	3 MEMORY CONTROL 1	1	600.	50,000.	0.050	0.5	0.3	1.7	0.0
13	3 MEMORY CONTROL 2	1	600.	50,000.	0.050	0.5	0.3	1.7	0.0
14	3 CHASSIS PROTECTION	1	1,300.	333,333.	0.050	4.5	0.3	1.7	0.0

										LSER				USER			
LN	RMS	NRTS	COND	LV	LV2	LSEV	USEV	LR	LR2	1	2	3	4	1	2	3	4
1	0.	0.000	0.000	0	0	0	0.0	0	0	0	0	0	0	0.0	0.0	0.0	0.0
2	0.	0.000	0.000	2	1	1	0.0	2	1	1	0	0	0	0.6	0.0	0.0	0.0
3	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0
4	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0
5	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0
6	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0
7	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0
8	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0
9	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0
10	0.	0.000	0.000	2	1	1	0.0	2	1	1	0	0	0	0.6	0.0	0.0	0.0
11	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0
12	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0
13	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0
14	50.	0.980	0.020	2	2	2	0.3	2	2	2	0	0	0	0.8	0.0	0.0	0.0

SUPPORT EQUIPMENT DEFINITION FILE

NUMBER OF LINE ITEMS OF SUPPORT EQUIPMENT = 2

LINE NUMBER	NOMENCLATURE	COST(CSE)	O&M COST FACTOR(COM)
1	ONE TEST SET	50,000.	0.010
2	GOVT FUR EQUIP	0.	0.0

CONTRACTOR DATA FILE

PARAMETER	VALUE
ACS: ACQUISITION COST/SYSTEM	12,000.
BTC: BASE LEVEL TRAINING COST	12,000.
DTC: DEPOT LEVEL TRAINING COST	12,000.
DCB: DATA ACQUISITION COST (BASE LEVEL MANUALS)	50,000.
DCD: DATA ACQUISITION COST (DEPOT LEVEL MANUALS)	100,000.
DCO: DATA ACQUISITION COST (OTHER)	6,000.
NPB: PAGES OF DATA (BASE LEVEL MANUALS)	71
NPD: PAGES OF DATA (DEPOT LEVEL MANUALS)	68
NPO: PAGES OF DATA (OTHER)	30
NI: NUMBER OF NEW INVENTORY ITEMS	4
CRSC: CONTRACTOR BASE RESUPPLY TIME - CONUS	240.
CRSO: CONTRACTOR BASE RESUPPLY TIME - OVERSEAS	400.

CDMC: CONTRACTOR REPAIR CYCLE TIME	720.
WPR: WARRANTY PRICE	106,000.

RELIABILITY GROWTH PROFILE

1.00	1.06	1.12	1.18	1.24	1.31	1.37	1.43	1.49	1.55
1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55
1.55									

SUPPORT EQUIPMENT REQUIREMENTS

LINE ITEMS OF SUPPORT EQUIPMENT REQUIRED AT BASE LEVEL

EQUIPMENT	QUANTITY	COST
ONE TEST SET	11	550,000.

LINE ITEMS OF SUPPORT EQUIPMENT REQUIRED AT DEPOT LEVEL

EQUIPMENT	QUANTITY	COST
ONE TEST SET	1	50,000.
GOVT FUR EQUIP	1	0.

SPARES REQUIREMENTS (DETAILED)

DEPOT LEVEL SPARES REQUIREMENTS

REPLACEABLE UNIT	SPARES	COST
DATA ACQUISITION	12	96,000.
MOTHERBOARD ASSY	1	700.
SIGNAL CONDITIONER 1	4	4,000.
SIGNAL CONDITIONER 2	5	5,000.
RTU 1553	4	5,600.
CPU AND MEMORY	5	7,000.
ADC CONTROL AND IO	4	4,000.
CHASSIS PSU DA	4	6,000.
MEMORY MODULE	17	68,000.
MEMORY STORAGE	16	24,000.
MEMORY CONTROL 1	6	3,600.
MEMORY CONTROL 2	6	3,600.
CHASSIS PROTECTION	2	2,600.

BASE LEVEL SPARES REQUIREMENTS (CONUS)

SYSTEMS/ BASE	BASES
17	2

LRU SPARES REQUIREMENTS

REPLACEABLE UNIT	SPARES/BASE	TOTAL	COST
DATA ACQUISITION	0	0	0.
MEMORY MODULE	0	0	0.

SYSTEMS/ BASE	BASES
41	40

LRU SPARES REQUIREMENTS

REPLACEABLE UNIT	SPARES/BASE	TOTAL	COST
DATA ACQUISITION	0	0	0.
MEMORY MODULE	0	0	0.

SYSTEMS/ BASE	BASES
60	20

LRU SPARES REQUIREMENTS

REPLACEABLE UNIT	SPARES/BASE	TOTAL	COST
DATA ACQUISITION	0	0	0.
MEMORY MODULE	0	0	0.

SYSTEMS/ BASE	BASES
287	6

SRU SPARES REQUIREMENTS

REPLACEABLE UNIT	SPARES/BASE	TOTAL	COST
MOTHERBOARD ASSY	0	0	0.
SIGNAL CONDITIONER 1	0	0	0.
SIGNAL CONDITIONER 2	0	0	0.
RTU 1553	0	0	0.
CPU AND MEMORY	0	0	0.
ADC CONTROL AND IO	0	0	0.
CHASSIS PSU DA	0	0	0.
MEMORY STORAGE	0	0	0.
MEMORY CONTROL 1	0	0	0.
MEMORY CONTROL 2	0	0	0.
CHASSIS PROTECTION	0	0	0.

SYSTEMS/ BASE	BASES
288	4

SRU SPARES REQUIREMENTS

REPLACEABLE UNIT	SPARES/BASE	TOTAL	COST
MOTHERBOARD ASSY	0	0	0.

SIGNAL CONDITIONER 1	0	0	0.
SIGNAL CONDITIONER 2	0	0	0.
RTU 1553	0	0	0.
CPU AND MEMORY	0	0	0.
ADC CONTROL AND IO	0	0	0.
CHASSIS PSU DA	0	0	0.
MEMORY STORAGE	0	0	0.
MEMORY CONTROL 1	0	0	0.
MEMORY CONTROL 2	0	0	0.
CHASSIS PROTECTION	0	0	0.

BASE LEVEL SPARES REQUIREMENTS (OVERSEAS)

SYSTEMS/ BASE	BASES
46	6

LRU SPARES REQUIREMENTS

REPLACEABLE UNIT	SPARES/BASE	TOTAL	COST
DATA ACQUISITION	0	0	0.
MEMORY MODULE	0	0	0.

SYSTEMS/ BASE	BASES
276	1

SRU SPARES REQUIREMENTS

REPLACEABLE UNIT	SPARES/BASE	TOTAL	COST
MOTHERBOARD ASSY	0	0	0.
SIGNAL CONDITIONER 1	0	0	0.
SIGNAL CONDITIONER 2	0	0	0.
RTU 1553	0	0	0.
CPU AND MEMORY	0	0	0.
ADC CONTROL AND IO	0	0	0.
CHASSIS PSU DA	0	0	0.
MEMORY STORAGE	0	0	0.
MEMORY CONTROL 1	0	0	0.
MEMORY CONTROL 2	0	0	0.
CHASSIS PROTECTION	0	0	0.

CONDEMNATION SPARES REQUIREMENTS

REPLACEABLE UNIT	SPARES	COST
DATA ACQUISITION	0	0.
MOTHERBOARD ASSY	1	700.
SIGNAL CONDITIONER 1	4	4,000.
SIGNAL CONDITIONER 2	4	4,000.

RTU 1553	3	4,200.
CPU AND MEMORY	4	5,600.
ADC CONTROL AND IO	4	4,000.
CHASSIS PSU DA	3	4,500.
MEMORY MODULE	0	0.
MEMORY STORAGE	19	28,500.
MEMORY CONTROL 1	5	3,000.
MEMORY CONTROL 2	5	3,000.
CHASSIS PROTECTION	1	1,300.

SPARES REQUIREMENTS (UNIT TOTALS)

REPLACEABLE UNIT	SPARES DEPOT	BASE	CONDEMNATION	TOTAL	TOTAL COST
DATA ACQUISITION	12	0	0	12	96,000.
MOTHERBOARD ASSY	1	0	1	2	1,400.
SIGNAL CONDITIONER 1	4	0	4	8	8,000.
SIGNAL CONDITIONER 2	5	0	4	9	9,000.
RTU 1553	4	0	3	7	9,800.
CPU AND MEMORY	5	0	4	9	12,600.
ADC CONTROL AND IO	4	0	4	8	8,000.
CHASSIS PSU DA	4	0	3	7	10,500.
MEMORY MODULE	17	0	0	17	68,000.
MEMORY STORAGE	16	0	19	35	52,500.
MEMORY CONTROL 1	6	0	5	11	6,600.
MEMORY CONTROL 2	6	0	5	11	6,600.
CHASSIS PROTECTION	2	0	1	3	3,900.

MANPOWER REQUIREMENTS
(MANHOURS PER YEAR)

YEAR	FLIGHT LINE	BASE	DEPOT
1	21.	0.	0.
2	56.	2.	104.
3	87.	3.	163.
4	116.	4.	217.
5	142.	5.	264.
6	149.	5.	277.
7	142.	5.	265.
8	137.	5.	254.
9	131.	4.	244.
10	128.	4.	239.
11	128.	4.	239.
12	128.	4.	239.
13	128.	4.	239.
14	128.	4.	239.
15	128.	4.	239.
16	128.	4.	239.
17	128.	4.	239.
18	128.	4.	239.
19	128.	4.	239.
20	128.	4.	239.

LRU OPERATING HOURS AND FAILURES

LINE REPLACEABLE UNIT

DATA ACQUISITION	YEAR	REMOVALS	RTOK'S	FAILURES	OP.HOURS
	1	8.2	0.2	8.0	101400.0
	2	22.0	0.4	21.6	288600.0
	3	34.4	0.7	33.8	476325.0
	4	45.8	0.9	44.9	666750.0
	5	55.9	1.1	54.8	857550.0
	6	58.6	1.2	57.5	945000.0
	7	56.1	1.1	55.0	945000.0
	8	53.8	1.1	52.7	945000.0
	9	51.7	1.0	50.6	945000.0
	10	50.6	1.0	49.6	945000.0
	11	50.6	1.0	49.6	945000.0
	12	50.6	1.0	49.6	945000.0
	13	50.6	1.0	49.6	945000.0
	14	50.6	1.0	49.6	945000.0
	15	50.6	1.0	49.6	945000.0
	16	50.6	1.0	49.6	945000.0
	17	50.6	1.0	49.6	945000.0
	18	50.6	1.0	49.6	945000.0
	19	50.6	1.0	49.6	945000.0
	20	50.6	1.0	49.6	945000.0

MEMORY MODULE	YEAR	REMOVALS	RTOK'S	FAILURES	OP.HOURS
	1	12.6	0.3	12.3	101400.0
	2	33.9	0.7	33.2	288600.0
	3	53.0	1.1	51.9	476325.0
	4	70.4	1.4	69.0	666750.0
	5	86.0	1.7	84.3	857550.0
	6	90.1	1.8	88.3	945000.0
	7	86.3	1.7	84.5	945000.0
	8	82.7	1.7	81.1	945000.0
	9	79.4	1.6	77.9	945000.0
	10	77.8	1.6	76.2	945000.0
	11	77.8	1.6	76.2	945000.0
	12	77.8	1.6	76.2	945000.0
	13	77.8	1.6	76.2	945000.0
	14	77.8	1.6	76.2	945000.0
	15	77.8	1.6	76.2	945000.0
	16	77.8	1.6	76.2	945000.0
	17	77.8	1.6	76.2	945000.0
	18	77.8	1.6	76.2	945000.0
	19	77.8	1.6	76.2	945000.0
	20	77.8	1.6	76.2	945000.0

ACQUISITION COST BREAKDOWN BY CATEGORY AND BY YEAR

CATEGORY	YEAR 1	2	3	4	5	6	7
INIT TRAIN	12000.	12000.	0.	0.	0.	0.	0.
DATA AQ	56000.	100000.	0.	0.	0.	0.	0.
ITEM ENT	0.	4800.	0.	0.	0.	0.	0.
DATA MGMT	3656.	2462.	0.	0.	0.	0.	0.
PRIM HW	7488000.	7488000.	7560000.	7632000.	7632000.	0.	0.
S.E.	0.	600000.	0.	0.	0.	0.	0.
INIT SP	58022.	58022.	58580.	59138.	59138.	0.	0.
INST	4992000.	4992000.	5040000.	5088000.	5088000.	0.	0.
WARRANTY	20998.	20998.	21200.	21402.	21402.	0.	0.

CATEGORY	YEAR 8	9	10	11	12	13	14
INIT TRAIN	0.	0.	0.	0.	0.	0.	0.
DATA AQ	0.	0.	0.	0.	0.	0.	0.
ITEM ENT	0.	0.	0.	0.	0.	0.	0.
DATA MGMT	0.	0.	0.	0.	0.	0.	0.
PRIM HW	0.	0.	0.	0.	0.	0.	0.
S.E.	0.	0.	0.	0.	0.	0.	0.
INIT SP	0.	0.	0.	0.	0.	0.	0.
INST	0.	0.	0.	0.	0.	0.	0.
WARRANTY	0.	0.	0.	0.	0.	0.	0.

CATEGORY	YEAR 15	16	17	18	19	20	21
INIT TRAIN	0.	0.	0.	0.	0.	0.	
DATA AQ	0.	0.	0.	0.	0.	0.	
ITEM ENT	0.	0.	0.	0.	0.	0.	
DATA MGMT	0.	0.	0.	0.	0.	0.	
PRIM HW	0.	0.	0.	0.	0.	0.	
S.E.	0.	0.	0.	0.	0.	0.	
INIT SP	0.	0.	0.	0.	0.	0.	
INST	0.	0.	0.	0.	0.	0.	
WARRANTY	0.	0.	0.	0.	0.	0.	

O & M COST BREAKDOWN BY CATEGORY AND BY YEAR

CATEGORY	YEAR 1	2	3	4	5	6	7
FLT LN MT	341.	918.	1435.	1909.	2331.	2443.	2338.
BASE MT	0.	30.	47.	63.	77.	81.	77.
DEPO MT	0.	6541.	10230.	13608.	16614.	17411.	16664.
ITEM MGMT	0.	600.	600.	600.	600.	600.	600.
DATA MGMT	9853.	16486.	16486.	16486.	16486.	16486.	16486.
PK & SHP	201.	71.	111.	147.	179.	188.	180.
S.E. MT.	0.	5653.	5752.	5853.	5954.	6000.	6000.

CATEGORY YEAR

	8	9	10	11	12	13	14
FLT LN MT	2242.	2153.	2107.	2107.	2107.	2107.	2107.
BASE MT	74.	71.	70.	70.	70.	70.	70.
DEPO MT	15977.	15346.	15022.	15022.	15022.	15022.	15022.
ITEM MGMT	600.	600.	600.	600.	600.	600.	600.
DATA MGMT	16486.	16486.	16486.	16486.	16486.	16486.	16486.
PK & SHP	173.	166.	162.	162.	162.	162.	162.
S.E. MT.	6000.	6000.	6000.	6000.	6000.	6000.	6000.

CATEGORY	YEAR						
	15	16	17	18	19	20	21
FLT LN MT	2107.	2107.	2107.	2107.	2107.	2107.	
BASE MT	70.	70.	70.	70.	70.	70.	
DEPO MT	15022.	15022.	15022.	15022.	15022.	15022.	
ITEM MGMT	600.	600.	600.	600.	600.	600.	
DATA MGMT	16486.	16486.	16486.	16486.	16486.	16486.	
PK & SHP	162.	162.	162.	162.	162.	162.	
S.E. MT.	6000.	6000.	6000.	6000.	6000.	6000.	

TOTAL COST SUMMARY (BY CATEGORY)

	UNDISCOUNTED COST	PRESENT VALUE COST
INITIAL TRAINING	24,000.	22,909.
DATA ACQUISITION	156,000.	146,909.
ITEM ENTRY	4,800.	4,364.
DATA MANAGEMENT	6,118.	5,894.
PRIME HARDWARE	37,800,000.	31,490,026.
SUPPORT EQUIPMENT	600,000.	545,455.
INITIAL SPARES	292,900.	244,006.
INSTALLATION	25,200,000.	20,993,351.
WARRANTY	106,000.	88,305.
TOTAL ACQUISITION COST	64,189,818.	53,541,220.
FLIGHT LINE MAINT.	39,291.	16,765.
BASE LEVEL MAINT.	1,285.	542.
DEPOT LEVEL MAINT.	277,631.	117,064.
ITEM MANAGEMENT	11,400.	5,019.
DATA MANAGEMENT	323,086.	147,757.
PACKING & SHIPPING	3,200.	1,466.
S.E.MAINTENANCE	113,211.	49,527.
TOTAL O&M COST	769,105.	338,139.
TOTAL LIFE CYCLE COST	64,958,923.	53,879,359.

TOTAL COST SUMMARY (BY YEAR)

SYSTEM OPERATIONAL LIFE = 20 YEARS

YEAR OF PROGRAM	UNDISCOUNTED COST	PRESENT VALUE COST
1	12,641,072.	12,641,072.
2	13,308,580.	12,098,715.
3	12,714,441.	10,507,813.
4	12,839,206.	9,646,298.
5	12,842,781.	8,771,808.
6	43,209.	26,829.
7	42,345.	23,902.
8	41,552.	21,323.
9	40,821.	19,043.
10	40,447.	17,154.
11	40,447.	15,594.
12	40,447.	14,177.
13	40,447.	12,888.
14	40,447.	11,716.
15	40,447.	10,651.
16	40,447.	9,683.
17	40,447.	8,803.
18	40,447.	8,002.
19	40,447.	7,275.
20	40,447.	6,613.
TOTAL	64,958,923.	53,879,359.

EXHIBIT 7C

SENSITIVITY ANALYSIS OF
COST PER SYSTEM INSTALLATION

SENSITIVITY ANALYSIS

SENSITIVITY PARAMETER SIN	UNDISCOUNTED TOTAL COST	PRESENT VALUE TOTAL COST
8000.000	64,958,923.	53,879,359.
12000.000	77,558,923.	64,376,034.
16000.000	90,158,923.	74,872,710.
20000.000	102,758,923.	85,369,385.

EXHIBIT 7D

SENSITIVITY ANALYSIS OF
SYSTEM OPERATING HOURS PER MONTH

SENSITIVITY ANALYSIS

SENSITIVITY PARAMETER OH	UNDISCOUNTED TOTAL COST	PRESENT VALUE TOTAL COST
25.000	64,958,923.	53,879,359.
50.000	65,516,032.	54,211,549.
75.000	66,046,840.	54,521,831.
100.000	66,589,049.	54,841,609.

APPENDIX A

PARAMETER REQUIREMENTS OF VARIOUS AGENCIES

APPENDIX A

PARAMETER REQUIREMENTS OF VARIOUS AGENCIES

A list of the parameter requirements of the various agencies involved with crash investigations is as follows:

(a) NTSB Recommendations A-78-27 through A-78-29

(b) USAF Statement of Need

(c) Statistical data for F-15, F-16, and A-10 accidents

(d) USN parameter list for F/A-18

(e) UK Civil Aviation Authority Spec 10

(f) List prepared by United Kingdom engineering advisor to the Civil Aviation Authority and the RAF

(g) Typical list for a United Kingdom high-performance military aircraft

NOTE: This list was not used in the generation of the recommended parameter list for the CSFDR study since it was not available until late.

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C.

ISSUED: April 13, 1978

Forwarded to:

Honorable Langhorne M. Bond
Administrator
Federal Aviation Administration
Washington, D.C. 20591

SAFETY RECOMMENDATION(S)
A-78-27 through 29

The National Transportation Safety Board is concerned about the number of accidents involving complex fixed wing, multiengine aircraft in air taxi and corporate/executive operations in which the accident circumstances remain unknown. Of the 194 fatal accidents in these operations from 1970 to 1977, cause has not been determined for 34 of the accidents. (See Attachment 1.) In addition to the accidents reflected in the data in Attachment 1, the Safety Board has recently investigated or is investigating five other accidents in the corporate/executive fleet alone1/ in which there appears to be little hope of determining definitive cause. These accidents, which have occurred within the past 18 months, have resulted in 26 fatalities.

With the continued growth in the numbers of complex multiengine aircraft in general aviation, particularly in corporate/executive operations and air taxi/commuter service, and the frequent operation in unfavorable

1/ Accidents under recent investigation:

Grumman Gulfstream II (G1159), N500J, Johnson & Johnson, Inc., Hot Springs, Virginia, September 26, 1976.

Lear 23, N332PC, Jet Avia Limited, Flint, Michigan, January 6, 1977.

Falcon 10, N60MB, Mountain Bell Co., near Denver, Colorado, April 3, 1977.

BH 125-600A, N40PC, Southern Company Services, Inc., McLean, VA, April 28, 1977.

Lear 25, N999HG, Champion Homes, near Sanford, NC, September 8, 1977.

environments, we believe that recorders are urgently needed. In fact, we believe that these recorders are as justified as those installed in the air carrier fleet in 1959. At that time, high speed, increased reliance on avionic equipment, and lack of eye witnesses combined to limit the investigative evidence and often eliminated chances of determining cause. These same factors are hindering today's investigations of accidents involving complex multiengine aircraft in air taxi and corporate executive operations.

Accident investigation experience with air carrier aircraft has proven that cockpit voice recorders (CVR) and flight data recorders (FDR) have been invaluable tools in identifying aircraft design deficiencies, common operational problems, shortcomings in the air traffic control system, and the effects of meteorological phenomena on aircraft performance. In almost every accident investigation involving these aircraft during the past 10 years, one or both of these recorders provided investigators with the clues necessary to piece together the circumstances of the accident. To its credit, the aviation community has always responded to these accident findings by instituting immediate remedial actions, or at the very least, by researching identified problem areas. The result has been continued improvement in aviation safety.

The value of the FDR, and in particular of the digital FDR, has become evident in the investigation of a number of air carrier accidents in which wind shear was a primary causal factor. The recorded data have provided a means for accurately determining the flight profiles and the direction and magnitude of winds. They have also provided sufficient information for programming aircraft simulators so that the condition encountered by the pilots could be reproduced in real time. Simulation based on FDR data has made it possible to explore human factors such as restricted visual cues which hinder prompt recognition of a developing descent rate and accurate assessment of the pitch attitude change required to arrest the descent before impact.

At least one manufacturer of corporate/executive aircraft has recognized the long-term value of the FDR and CVR and is providing space and power for the FDR and installing a CVR in every aircraft of this category manufactured. As corporate flying becomes an ever-increasing part of the transportation system, corporate operators are also discovering that it is to everyone's advantage to install CVR's and FDR's aboard their aircraft. A corporate flight department's operation is invariably suspect in the eyes of general aviation antagonists after an accident for which the precise cause is unknown.

The economic benefits of the FDR and CVR are becoming apparent as well. The inability to properly determine the cause of an accident can be costly, not only because of the failure to determine proper preventive measures, but also because of liability of the manufacturers, the operator, and the Government.

In addition, corporations and air taxi operators are providing transportation in lieu of available Part 121 air carrier transportation. These passengers are not being afforded a level of safety equivalent to that of air carriers. The Safety Board believes an equivalent level can only be effected in the long term by the installation of flight recorders.

The Safety Board believes that an industry which has made the micro-computer a household tool could develop a reasonably priced, light weight, small-volume, solid state digital flight data recorder and an equally inexpensive cassette type cockpit voice recorder which would serve the intent of the flight recorder requirement. In fact, one manufacturer is developing a very small digital flight data recorder under contract for the U.S. Army which will employ the latest electronic technology and will be capable of recording over 30 minutes of data for more than 15 parameters.

This system is to use a microprocessor to decide which data should be stored and when, and a nonvolatile solid-state memory instead of recording tape. Because no recording tape is used, the system will be virtually maintenance free. Whereas, current FDR's of the scribed metal foil variety record only four variable parameters, cost $15,000 to $20,000 to install, and weigh 40 pounds, the U.S. Army plans for their new unit to cost $10,000, including installation, on a limited production schedule and weigh about 7 pounds.

Although the unit being developed under this contract does not have voice recording capability, discussions with equipment suppliers indicate that the technology is available to produce a similar recorder capable of recording both voices and digital data on aircraft performance.

In addition to new flight recorder standards for certain aircraft operating under 14 CFR 91 and 14 CFR 135, the Safety Board believes that the current standards for aircraft operating under 14 CFR 121 should be revised and updated to reflect modern needs and the technological state of the art. Although the data that they presently provide are extremely valuable, FDR's could record additional parameters with more useful accuracy and CVR's could produce better quality voice recordings at minimal cost if modern technology were employed. A list of requirements which we believe to be feasible is attached. (See Attachment 2)

In view of the above, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Develop, in cooperation with industry, flight recorder standards (FDR/CVR) for complex aircraft which are predicated upon intended aircraft usage. (Class II, Priority Action) (A-78-27)
>
> Draft specifications and fund research and development for a low cost FDR, CVR, and composite recorder which can be used on complex general aviation aircraft. Establish guidelines for these recorders, such as maximum cost, compatible with the cost of the airplane on which they will be installed and with the use for which the airplane is intended. (Class II, Priority Action) (A-78-28)
>
> In the interim, amend 14 CFR to require that no operation (except for maintenance ferry flights) may be conducted with turbine-powered aircraft certificated to carry six passengers or more, which require two pilots by their certificate, without an operable CVR capable of retaining at least 10 minutes of intracockpit conversation when power is interrupted. Such requirements can be met with available equipment to facilitate rapid implementation of this requirement. (Class II, Priority Action) (A-78-29)

KING, Chairman, McADAMS, HOGUE, and DRIVER, Members, concurred in the above recommendations.

By: James B. King
Chairman

ATTACHMENT 1

FATAL ACCIDENTS
U.S. GENERAL AVIATION
MULTI-ENGINE FIXED WING
1970-1977

EXCLUDES ACCIDENTS WITH NO CAUSAL ASSIGNMENT
AS OF 3/14/78

BROAD Cause/Factor	FATAL ACCIDENTS Cause	Factor	Total
Pilot	766	169	779
Personnel	76	37	111
Airframe	19	3	22
Landing Gear	1	1	2
Powerplant	110	15	120
Systems	20	6	26
Instruments/ Equipment & Accessories	3	7	10
Airport/Airways/Facilities	3	10	13
Weather	37	416	442
Terrain	24	160	184
Miscellaneous	22	9	31
Undetermined	91	0	91

Total No.
Fatal Accidents 917

FATAL ACCIDENTS
OF
UNDETERMINED CAUSE
GENERAL AVIATION
MULTI-ENGINE FIXED WING
1970-1977

Category	Number of Undetermined Accidents	Number of Fatalities
Air Taxi	21	80
Corporate/Executive	13	47
Business	16	37
Pleasure/ Personal Transport	28	79
Miscellaneous (Ferry/Instruction/Unknown)	13	36
Total	91	279

ATTACHMENT 2

FLIGHT RECORDER STANDARDS VIEWED AS FEASIBLE
BY NATIONAL TRANSPORTATION SAFETY BOARD

COCKPIT VOICE RECORDER to record intra-cockpit voice communications with retention of at least 10 and preferrably 15 minutes of recorded data at time of power interruption.

-- Require on turbine-powered aircraft carrying 6 passengers or more, certificated for two-pilot operation that are in present service operating under 14CFR91 or 14CFR135.

MINI FLIGHT DATA RECORDER to record at least 5 variable parameters and one binary signal as a function of time. The minimum parameters are: Indicated Airspeed, Pressure Altitude, Magnetic Heading, Vertical Acceleration, Longitudinal Acceleration and the keying of any air/ground communication equipment. Recording media or memory should retain the last 10 minutes of data at time of power interruption.

-- Require on newly manufactured multi-engine aircraft certificated to carry 6 to 9 passengers and single-pilot operation under 14 CFR91 or 14CFR135.

-- Require on newly manufactured multi-engine aircraft certificated to carry 10 passengers or more and single-pilot operation under 14CFR91.

COMPOSITE FLIGHT DATA and COCKPIT VOICE RECORDER or individual installation of Cockpit Voice Recorder and Mini Flight Data Recorder which will satisfy the requirements for both equipment as described above.

-- Require on newly manufactured turbojet aircraft certificated to carry 6 passengers or more and two pilot operation under 14CFR91 or 14CFR135.

-- Require on all multi-engine aircraft, including those presently in service, certificated to carry 10 passengers or more and operating under 14CFR121, 14CFR127, or 14CFR135, except for those larger air carrier aircraft required to have recorders by the present rule 14CFR121.343.

BASIC EXPANDED PARAMETER FLIGHT DATA RECORDER as described in 14CFR 121.343 paragraph (a)(2), and COCKPIT VOICE RECORDER as described in 14CFR121.359.

-- Require on all newly manufactured large aircraft certificated for operations above 25,000 feet altitude or that are turbine engine powered regardless of the date of issue of the aircraft's type certificate that operate under 14CFR121.

EXPANDED PARAMETER FLIGHT DATA RECORDER recording parameters described in Enclosure 1 to Safety Recommendations A74-15 thru 17 dated March 1, 1974, plus any dedicated parameters which may be desirable because of unique features of the specific aircraft configuration and type design, and COCKPIT VOICE RECORDER as described in 14CFR 121.359.

-- Require on all large aircraft certificated for operations above 25,000 feet altitude or that are turbine engine powered for which a new type certificate is issued that operate under 14CFR121.

TABLE I

PARAMETERS IN ORDER OF PREFERENCE

NOTE: It is the opinion of TE-60 personnel that data compression can be used if the last 5 minutes of recorded data are not compressed, but are stored at the minimum allowable sampling rate. This will allow reconstruction of the rotation profile on takeoff accidents, and landing profile on approach accidents. (All of this does not obviate the need for a DFDR record (compressed or not) of the last takeoff and landing prior to the accident, as well as a record of the preflight exercise of the flight controls to maximum deflection).

Essential Parameters For All Flight Data Recorders

	PARAMETER	RANGE	MINIMUM ACCURACY (COCKPIT INSTRUMENT DISPLAY TO DFDR READOUT)	MINIMUM SAMPLING RATE	MAX. INTERVAL IF COMPRESSION USED
1.	Time	-	$\pm$0.125 percent per hour	1 per minute	Time to the second must be tied to each data point
2.	Airspeed	V_{SO} to V_D (KIAS)	$\pm$ 2 percent	1 per second	10 knots
3.	Altitude	-1,000 feet to max. certificated altitude of aircraft	$\pm$100 to $\pm$700 feet (see Table 1, TSO C51a)	1 per second	100 feet
4.	Magnetic Heading	360 degrees	$\pm$2 degrees	1 per second	2 degrees
5.	Vertical Acceleration	-3g to +6g	$\pm$0.2g	4 per second	0.1g
6.	Radio Transmitter Keying (Discrete)	-	-	1 per second	Any change in state
7.	Longitudinal Acceleration	$\pm$1g	$\pm$0.05g	2 per second	0.05g
8.	Thrust/Power	Full Range Forward	$\pm$2 percent	1 per second	2 percent
9.	Primary Control Surfaces: Pitch (elevator/stabilizer) Roll (aileron/spoiler) Yaw (rudder)	Full Range	$\pm$2 degrees (unless aircraft uniquely requires higher accuracy)	1 per second	2 degrees (unless aircraft uniquely requires finer interval)
10.	Pitch Attitude	-50 to +25 degrees	$\pm$2 degrees	1 per second	2 degrees
11.	Roll Attitude	$\pm$180 degrees	$\pm$2 degrees	1 per second	2 degrees
12.	Stabilizer Trim Position (if applicable)	Full Range	$\pm$1° or $\pm$5 percent, whichever is greater	1 per 2 seconds	0.1 degree

PARAMETER	RANGE	MINIMUM ACCURACY (COCKPIT INSTRUMENT DISPLAY TO DFDR READOUT)	MINIMUM SAMPLING RATE	MAX. INTERVAL IF COMPRESSION USED
.* Trailing Edge Flap Surface Position	Full Range or Each Discrete Position	±3 degrees (unless discrete)	1 per 2 seconds	3 degrees (unless discrete)
.* Leading Edge Flaps/Slat Position (Discrete)	Each Discrete Position	-	1 per 2 seconds	Any Change in State
.* Spoiler/Speedbrake Position (Discrete)	-	-	1 per second	Stowed/deployed
.* Autopilot/Flight Director Mode (Discrete)	-	-	1 per second	Any Change in State
. Angle of Attack	-20° to +40°	±1°	1 per second	1 degree
.* Squat Switch Position (Discrete)	-	-	1 per second	Any Change in State
. Lateral Acceleration	±1g	±0.05g	2 per second	0.05g
.* Thrust Reverser Position Each Engine (Discrete)	Stowed and Full Reverse	-	1 per second	Any Change in State
1.* Marker Beacon Passage (Discrete)	-	-	1 per second	Any Change in State
22. Localizer	±2 dots	±10 percent	1 per second	0.1 dot
23. Glideslope	±2 dots	±10 percent	1 per second	0.1 dot
24. Radio Altitude	-10 to 2,000 feet	±5 feet or 5 percent, whichever is greater	1 per second	5 feet
25. Indicated Air Temperature	-60°C to +60°C	±2°C	1 per 2 seconds	2 degrees
26.* Fire Warning (Discrete)	-	-	1 per second	Any Change in State
27.* Hydraulic Pressure (Discrete)	-	-	1 per second	Any Change in State
28.* Pressurization (Discrete)	-	-	1 per second	Any Change in State
29.* Electrical (Discrete)	-	-	1 per second	Any Change in State

TABLE II

WORD LENGTHS USED IN MOST §121 OPERATIONS
AND EXAMPLES OF RESULTING RESOLUTIONS

PARAMETER	BITS (N)	EXAMPLE RANGE	RESOLUTION FOR N BITS AND EXAMPLE RANGE	RESOLUTION FOR 8 BITS AND EXAMPLE RANGE
Airspeed	12	0 - 400 KIAS	0.1 KIAS	1.6 KIAS
Fine Altitude	12	-1,000 to 50,000 ft	1 foot	200 feet*
Coarse Attitude	7 or 12			
Magnetic Heading	10	360°	0.35 degrees	1.4 degrees
Vertical Acceleration	10	-3g to +6g	0.01g	0.04g
Longitudinal Acceleration	12	-1 to +1g	0.0005g	0.008g
Pitch Attitude	10	-75° to +75°	0.15 degrees	0.6 degrees**
Roll Attitude	10	-180° to +180°	0.35 degrees	1.4 degrees
Engine Thrust	12	0 - 120 units	0.03 units	0.5 units
Pitch Control	10	-30° to +30°	0.06 degrees	0.24 degrees
Lateral Control	10	-30° to +30°	0.06 degrees	0.24 degrees
Yaw Control	10	-30° to +30°	0.06 degrees	0.24 degrees
Trailing Edge Flap	10	0 - 60°	0.06 degrees	0.24 degrees
Air Temperature	12	-100 to +50°C	0.04°C	0.6°C
Pitch Trim	12	-30° to +30°	0.015°	0.24 degrees
Lateral Acceleration	10	-1 to +1g	0.002g	0.008g
Angle of Attack	10	-20° to +40°	0.06 degrees	0.24 degrees

* Not acceptable.

** A pitch range of -50° to +25° gives a resolution of 0.3° using 8 bits. We consider 0.3° acceptable.

NORMALAIR-GARRETT LIMITED
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Crash Survivable Flight Data Recorder Study - Questionnaire - Sheet 1

Normalair-Garrett Ltd and the Airesearch Manufacturing Company of California are jointly carrying out a study, under contract to the United States Air Force Systems Command - Wright Patterson Air Force Base, to determine the optimum crash survivable flight data recording system for military aircraft.

One aspect of the study is to collect and evaluate a wide range of information covering accident investigation requirements; maintenance recording; availability of signals; data compression; cost, size, weight, reliability/maintainability of recording equipment, and typical mission profiles.

The A-10, F-15 and F-16 are to be considered typical aircraft for the purpose of the study. However we are also required to determine whether it is feasible to produce a standard system suitable for both fighter/trainer and transport/bomber aircraft.

We would be very grateful if you would provide us with as much of the information indicated on the attached sheets as possible. If there is other information that you consider relevant to the study please provide that also.

Please reply to the above address and if you have any queries telephone Nick Bullock (Project Engineer) on 0935 26151 Ext 234.

NORMALAIR-GARRETT LIMITED
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your ref.

date

Crash Survivable Flight Data Recorder Study - Questionnaire - Sheet 2

Details of person(s) and organisation responding:

Name J.R. STURGEON Job Title Load Data Acquisition and Analysis

Name .... Job Title ....

Name .... Job Title ....

Organisation STRUCTURES RAE

Address Farnborough Hants

Telephone Aldershot 24461 x5645 or 5106

General Remarks Also advise to CAA & RAF on Crash Recorder Policy.

No crash recording system is viable unless a complete flight is replayed on analogue traces and visually inspected about 10 times per year. No other system provides evidence of intermittent faults in transducers or the recording system. This must be possible without removing equipment from the aircraft i.e a 'milking' system.

Ref. NJOB/EPF/407 Issue 1

Crash Survival Flight Data Recorder Study - Questionnaire - Sheet 3

Accident Investigation Questions - I

1. Parameters

Sheet 4 and 5 list various parameters. Please add any others that you regard as important and indicate the order of priority, the required sampling rate, the total signal range and the required accuracy and resolution plus any remarks. Under Resolution-Fine please give the resolution that would be needed in an accident investigation situation and under Resolution-Course that which would be acceptable under steady state conditions. 10 bit resolution essential; 8 bit accuracy acceptable if individual digitising steps are approx equal

2. Duration

2.1 Minimum recording duration .... hours .... flights.
To previous approach & landing

2.2 Please indicate how probability of determining cause of accident would be affected if recording duration was:

last 10 minutes ...., last 20 minutes .... reliability would be very bad as confidence in data
last 30 minutes ...., one complete flight ..Good..

2.3 How would the figures in paras 2.1 and 2.2 be altered if maintenance data were available in addition to crash parameters.

Not at all unless maintenance data survi

3. Survival

3.1 What crash protection levels are necessary for high performance military aircraft.

TSO C51A

3.2 What recorder data survival rate would those levels provide ..95%...

3.3 What is the optimum location for the recorder Well behind the wing away from heavy metallic items eg spars.

3.4 If an ejectable recorder is used what protection levels are required and what would survival rate be. Poor

....

3.5 What proportion of aircraft crash into water of a depth that prevents recovery of recorded data.

Low in Europe .. Mainly a muddy water pro
Bleeper essential.

4. General

4.1 In what proportion of accidents is recorded data the principal means of determining the causes. Identification of pilot error is not determining the cause of an accident. Most accidents have at least 3 causes and an initial trigger: If available an accident recorder usually changes the course of the investigation and the remedial measures.

Ref. NJOB/BRB/497 Issue 1

AIRESEARCH MANUFACTURING COMPANY

81-17693

Crash Survival Flight Data Recorder Study - Questionnaire - Sheet -

Accident Investigation Questions - I cont

4.2 In what proportion of accidents would the addition of audio ~~[illegible]~~ help to a determination of the cause. Perhaps 50% on civil, much lower on Military aircraft.

4.3 If audio is included should it be pilot's tels., pilot's tels and mic, free area mic etc, and what should duration be. Two (or more) channels ~~or so~~ are highly desirable e.g. ~~pilots~~ crew mikes and free area. One ~~area~~ channel must be crew ~~and give~~ mike.

4.4 In what proportion of accidents does determination of the cause prevent a repetition.
No statistics available as it is politically unacceptable to have two accidents with the same cause.

Ref. NJOB/BRB/L57 Issue 1

AIRESEARCH MANUFACTURING COMPANY

ngl

Crash Survivable Flight Data Recorder Study - Questionnaire - Sheet [illegible]

Accident Investigation Questions - II   Fighter type aircraft

Parameter	Priority	Sample Rate	Signal Range	Accuracy	Resolution Fine	Resolution Course	Remarks
Angle of attack	3	4-8			[illegible]	[illegible]	
Altitude (pressure)	1	1-2					
(radio)	3	1					
Normal acceleration (Loadfactor)	1	8-16	-5 to +10g	Very good			at C of G longitudinal ± 24"
Roll rate or acc	3	8-16	20 rad/sec²				
Calibrated airspeed	1	1-2					
Yaw rate or acc	3	8-16	3 rad/sec²				
Pitch rate or acc	3	8-16	5 rad/sec²				
Elevator position	2	8-16					
Aileron position	2	8-16					
Rudder position	2	8-16					
Roll (bank) angle	1	4-8					
Pitch attitude	1	4-8					
Vertical velocity	—						
Heading (magnetic)	2	1-2					
(gyro)		1					
Engine r.p.m	3	1					
Engine EGT	3	1					
Engine fuel flow	3	1					
Hydraulic pressure	3	1					
Utility hydraulic pressure							
Generator output	4	4	0-200%				
Invertor output	4	4	0-200%				
Oil pressure	—						
Fuel quantity	—						
DME ('Distance' Measuring Equip)	—						
Oxygen pressure	4	1					
Ejector seat operation	—						
Airframe stresses	—	16-~~64~~					
Others							
Engine EPR	1	.1-2					
~~Lateral acceleration~~	~~1~~	~~8-16~~	~~±1.5g~~	~~desirable horizontal~~			~~desirable at C of G axis~~
Cabin pressure	3						
~~Pitch acc~~	~~3~~						
~~Roll acc~~	~~3~~						
~~Yaw acc~~	~~3~~						
Longitudinal acc	3		±1.5g				

Data should have similar error pattern to pilots instruments except normal acceleration

Ref. NJOB/BRB/497   Issue 1

ngl

Crash Survival Flight Data Recorder Study - Questionnaire - Sheet 6

Accident Investigation Questions - III

Parameter	Priority	Sample Rate	Signal Range	Accuracy	Resolution	Remarks
Side slip angle						
Throttle position						
Afterburner - range, -nozzle position						
Rudder pedal - position or force						
Stick-position or force						
Mach number	—					
Flap position	1					
Landing gear position	3					
Speed brake position	2					
Oil Quantity						
Air Data Computer Status						
Fire Control System Status						
Press to transmit						
Lateral acceleration	1	8-16	±1.5g	[illegible]		Accurate C of g, [illegible] ±1[illegible]
Reverse						
Leading edge high lift devices - control position	2					
Pitch trim						
Temperature type?						
Undercarriage						
ILS Localiser	3					
ILS Slideslope	3					
Warnings						
Fire (each engine and APU)						
Cabin pressure	3					
Warning leading to engine shutdown						
Fuselage smoke						
Essential Pneumatic Power						
Autopilot						
Engagement of each control axis	2					
Selection of each 'Capture' & 'Acquire' mode	3					
Others						

Ref. NJCB/BFB/4?? Issue 1

Crash Survivable Flight Data Recorder Study - Questionnaire - Sheet 7

Airframe Information - I

Please supply as much of the following information as possible for each aircraft under consideration. Use whatever format is most convenient to you.

1. Aircraft type.

2. Maximum acceptable size, mass, and power consumption of the acquisition system and the memory unit.

3. Optimum location of memory unit for crash survival.

4. Possible positions for memory unit and acquisition system.

5. Environmental conditions obtaining at locations in para 4.

6. Crash conditions i.e. shock levels, impact and crush forces, fire temperature and duration.

7. Signal availability.
   The following data is sought for each of the parameters listed on Sheet 9 and any other parameters you regard as desirable for accident investigation purposes.

   7.1 Signal range and type.

   7.2 Max rate of change.

   7.3 Accuracy.

   7.4 Repeatability.

   7.5 Resolution.

   7.6 Reliability.

   7.7 Maintainability.

   7.8 Any other data considered relevant.

   7.9 If the signals are not available on digital data highway where can they be obtained - info wanted for cabling considerations.

   7.10 If no signal is available what are the problems involved in fitting a transducer and what would the weight penalty be.

   7.11 Alternatively can the information be deduced from other parameters - please indicate the cases in which this would be a better solution than fitting a transducer.

   7.12 Normal signal profile.

Ref. AJGB/BRB/407 Issue 1

Crash Survivable Flight Data Recorder Study - Questionnaire - Sheet 6

Airframe Information - I cont

7.13 Interelationship between signals in normal flight (this is for the purpose of determining whether data compression is possible).

Very strong crosscoupling effects are normal

8. Maintenance data

8.1 What parameters should be recorded for maintenance purposes.

8.2 Please provide the information indicated in para 7 for the maintenance data signals.

Ref. MJOB/BRB/497 Issue 1

Crash Survivable Flight Data Recorder Study - Questionnaire - Sheet 9

Parameters

Angle of attack
Altitude (pressure)
(radio)
Normal acceleration
(Load factor)
Roll rate
Calibrated airspeed
Yaw rate
Pitch rate
Elevator position
Aileron position
Rudder position
Roll (bank) angle
Pitch attitude
Vertical velocity
Heading (magnetic)
(gyro)
Engine r.p.m
Engine EGT
Engine fuel flow
Hydraulic pressure
Utility hydraulic
pressure
Generator output
Inverter output
Oil pressure
Fuel quantity
DME (Distance Measuring
Equipment)
Oxygen pressure
Ejector seat operation
Airframe stresses
Side slip angle
Throttle position
Afterburner - range
nozzle position

Rudder pedal position
or force
Stick position or force
Mach number
Flap position
Landing gear position
Speed brake position
Oil quantity
Air Data Computer
Status
Fire Control System
Status
Press to transmit
Lateral acceleration
Reverse
Leading edge high lift
devices - control posi-
tion
Pitch trim
Temperature type?
Undercarriage
ILS Localisor
ILS Glideslope
Warnings
Fire (each engine & APU)
Cabin pressure
Warnings leading to engine
shut down
Fuselage smoke
Essential Pneumatic Power
Autopilot
Engagement of each control
axis
Selection of each 'Capture'
& 'Acquire' mode

Ref. NJOB/BRB/497 Issue 1

ngl

Crash Survivable Flight Data Recorder Study - Questionnaire - Sheet 10

Operational Questions - I

Please respond in whatever format is most convenient to you.

1. What is the maximum acceptable size, mass and power consumption for the accident recorder and the acquisition unit.
2. If maintenance recording is undertaken what is the optimum means of retrieving the data e.g. removing accident recorder memory from aircraft, 'milking' recorder on the aircraft, a separate quick access recorder.
3. If milking is undertaken what is maximum acceptable 'milking' time.
4. How quickly is maintenance data analysis required.
5. What parameters should be recorded for maintenance purposes.
6. What recording duration is required.
7. What is a typical mission profile.
8. Is there a definable relationship between certain parameters during normal flight.
9. What are the best positions for fitting the acquisition unit and recorder(s).
10. What reliability is required from an accident recording system and a maintenance recording system.
11. What maintainability is required.
12. What savings can be achieved by employing a maintenance recording system.
13. What are the implications of using the same equipment on fighter/trainer aircraft and transport/bomber aircraft.
14. How do the responses to the above question differ for transport/bomber aircraft.

Ref. NJOB/BRB/407 Issue 1

Crash Parameters Sampling Rates and Accuracy

The parameters, sampling rates, and accuracies shown on the attached tables apply to a typical high-performance military aircraft. Since the tables were produced, certain low sample rate engine parameters have been added; these are chiefly temperatures.

The actual aircraft type to which the figures relate cannot be divulged because the information is restricted.

PARAMETER NUMBER	P A R A M E T E R	SYMBOL	EXPECTED SOURCE	SIGNAL CHARACTERISTICS	MAX. SIGNAL RANGE	SAMPLING RATE (sec^{-1})	MIN. BIT RESOLUTION
I 1	Pressure Altitude (Millibars)	Q.N.H.	A.D.C.	Digital	15 data bit	1	10
I 2	Calibrated Airspeed	V	A.D.C.	Digital	11 data bit	1	10
I 3	Secondary Heading	ψ true	SAHR	Digital	14 data bit	1	10
I 4	Secondary Bank	Φ	SAHR	Digital	13 data bit	1	10
I 5	Secondary Inclination	Θ	SAHR	Digital	12 data bit	1	10
I 6	Normal Acceleration	$\ddot{R}$	extra sensor	Analogue DC	- 5 to + 12 g	8	10
I 7	True Angle of Attack	α	A.D.C.	Digital	11 data bit	2	8
I 8	Roll Rate	p	CSAS	Analogue DC	± 10 V	16	10
I 9	Pitch Rate	q	CSAS	Analogue DC	± 10 V	4	10
I 10	YAW Rate	r	CSAS	Analogue DC	± 10 V	4	10
I 11	Taileron Position Port	n	CSAS	Analogue DC	± 10 V	4	10
I 12	Taileron Position STBD	n	CSAS	Analogue DC	± 10 V	4	10
I 13	Outboard Spoiler Pos. Port	ξ SP	CSAS	Analogue DC	± 10 V *)	1	5
I 14	Inboard Spoiler Pos. STBD	ξ SP	CSAS	Analogue DC	± 10 V	1	5
I 15	Rudder Position	ζ	CSAS	Analogue DC	± 10 V	4	10
I 16	Stick demand roll	-	CSAS	Analogue DC	± 10 V	2	5
I 17	Stick demand pitch	-	CSAS	Analogue DC	± 10 V	2	5
I 18	Rudder Pedal Position	-	CSAS	Analogue DC	± 10 V	1	5

PARAMETER NUMBER	PARAMETER	SYMBOL	EXPECTED SOURCE	SIGNAL CHARACTERISTICS	MAX. SIGNAL RANGE	SAMPLING RATE (sec^{-1})	MIN. BIT RESOLUTION
I 19	Wing Sweep Position	λ	Wing Sweep System	Analogue DC	± 10 V 1mA	1	4
I 20	Radio Height	he	Rad Alt	Digital	13 data bit	1	10
I 21	TF Command	-	TF Radar	Digital	8 data bit	2	10
I 22	Autopilot Mode	-	Autopilot Control Pan.	5 Discretes max.	-	1	5
I 23	Elapsed time after oleo switch operation	t	Internal	Digital	binary 15 sec /bit	1	10
I 24	Glide Slope Deviation	G.P.	ILS or SETAC	Analogue DC	± 10 V	1	9
I 25	Localiser Deviation	LLZ	ILS or SETAC	Analogue DC	± 10 V	1	9
I 26	Voice Audio		P'lt & Navs CC Stations	Voice	140 mV - 1.4V RMS 300Hz to 3 kHz	continuous	
I 27	HP Rotor Shaft RPM (Port)	NH	A/C INTERFACE	Frequency	4390,5 Hz to 10539,6 Hz 0,2 V rms at 1000 Hz app. 3 V rms at 10.000 Hz max current 10 m A, 1000 Ω load	1	10
I 28	HP Rotor Shaft RPM (Stbd)	NH	A/C INTERFACE	Frequency		1	10

PARAMETER NUMBER	P A R A M E T E R	SYMBOL	EXPECTED SOURCE	SIGNAL CHARACTERISTICS	MAX. SIGNAL RANGE	SAMPLING RATE (sec^{-1})	MIN. BIT RESOLUTION
I 29	Power Lever Pos. (Port)	TBD	TBD	Analogue		1	5
I 30	Power Lever Pos. (Stbd)	TBD	TBD	Analogue		1	5
I 31	Jet Pipe Pressure (Port)	P 7	Synchro repeaters of Pilot Indicators	Synchro	TBA	1	7
I 32	Jet Pipe Pressure (Stbd)	P 7				1	7
I 33	Nozzle Area (Port)	A 7				1	5
I 34	Nozzle Area (Stbd)	A 7				11	5

Recording Capability = 64 words/sec = 60 samples/sec +(2 Calibration words for each data conditioning channel + 2 Block Marker words) per second
(6 samples/sec recovered by sharing 5 bit words)

Bit Rate = 600 Bits/Sec. i.e. a Spare Bit Capacity of 115 Bits/Sec at 1 7/8 ips and 410 bits/inch. ITEM (13 + 14, 16 + 17, 29 + 30,
33 + 34, 18 + 22)

There are: 47 off - 10 Bit Words
2 off - 9 Bit Words
2 off - 8 Bit Words
2 off - 7 Bit Words
12 off - 5 Bit Words
1 off - 4 Bit Words
+ 9 Engine Events
+ 7 CSAS Events (discretes)
+ 2 ILS Events
+ 1 oleo switch operation

1) Discretes

binary 1 = + 28V CWS System Signals
binary 0 = 0V
Unit Faults: binary 1 = short circuit Maintenance Panel Signals
binary 0 = open circuit

digital "0" 0V ± 0,5 V
digital "1" 5V + 0,5 V
\- 1,0 V
Autopilot modes

LIST OF EVENTS

No.	Sample Rate	Bits	Event	
1	1	1	Engine Vibration Port (red)	
2	1	1	Engine Vibration Starboard (red)	
3	1	1	Ice Warning	
4	1	1	Hydraulic Pressure Port	
5	1	1	Hydraulic Pressure Starboard	
6	1	1	Cabin Pressure	
7	1	1	Fuel Content Low Warning	
8	1	1	Fire Warning Port	
9	1	1	Fire Warning Starboard	
10	1	1	Pitch SAS-AD 2nd Failure	
11	1	1	Roll SAS-AD 2nd Failure	
12	1	1	Yaw SAS-AD 2nd Failure	CSAS
13	1	1	Pitch-Roll for Emergency Control	
14	1	1	Taileron f. 2nd Failure	
15	1	1	Rudder f. 2nd Failure	
16	1	1	Flag Warning Sigs. Glide Slope	
17	1	1	Flag Warning Sigs. Localizer	
18	1	1	Flaps Slat Actuation	CSAS
19	1	1	Oleo Switch Operation	

FLIGHT DATA RECORDER PARAMETER LIST

The following parameters, taken from the Statement of Need (SON) for Flight Data Recorders, dated 27 August 1979, **must be considered as a baseline for the Flight Parameter Evaluation.**

- Angle-of-attack
- Altitude
- Normal load factor
- Roll rate
- Calibrated airspeed
- Yaw rate
- Pitch rate
- Elevator position
- Aileron position
- Rudder position
- Bank angle
- Pitch attitude
- Sink rate (vertical velocity)
- Heading
- Engine RPM
- Engine EGT
- Engine fuel flow
- Hydraulic pressure
- Utility hydraulic pressure
- Generator output
- Inverter output
- Oil pressure
- Fuel quantity

Given storage capacity, the following parameters are highly desirable for inclusion:

- Sideslip angle
- Throttle position
- Afterburner (range, nozzle position)
- Rudder pedal (position or force)
- Stick (position or force)
- Mach number
- Flap position
- Landing gear position
- Speed brake position
- Oil quantity
- Air Data Computer Status
- Fire Control System Status

SECTION D - Preservation/Packaging/Packing

(i) The contractor shall provide preservation, packaging and packing which shall afford adequate protection against physical damage during shipment for all deliverable items in accordance with Level C of MIL-STD-794.

ACCIDENT NO.__________ A/C TYPE A-10 PILOT SURVIVED 53%

CATEGORY ACCIDENT__________

CAUSAL FACTORS/CERTAINTY 17 accidents

1	5
2	6
3	7
4	8

PARAMETERS UTILITY (H, M, L)/AVAILABILITY (AVAILABLE, N/A)

TIME 18%	STICK POS 53%	FUEL FLOW 24%
AOA 59%	RUDDER RED POS 35%	OIL PRESS. 24%
ALT (BARO) 53%	ELEV. POS. 47%	A/B POS.
CAS 47%	AILERON POS. 59%	OAT
MACH 18%	RUDDER POS. 65%	ALT (RDR) 18%
PITCH ATT 65%	THROTTLE POS 29%	HYD PRESS 53%
BANK ATT 65%	N_1 53%	UTIL HYD PRES 29
HEADING 18%	N_2 47%	GEN 24%
YAW RATE 71%	EGT 47%	INVERTER 18%
NORM LOAD 47%	CDP 6%	TRIM 47%
FUEL TOT 12%	CADC -	MASTER CAUT 53%
FUEL/TANK 6%	CAS PITCH 35%	FIRELITE 12%
GEAR POS	ROLL 47%	EPU (APU) 12%
FLAP POS 18%	YAW 35%	STARTER 6%
SB POS 47%	PADDLE SWITCH 18%	SAS 6%
SLAT POS 65%	ANTI SKID FAIL	
COMM TRANSMIT 12%	NAV STATUS	

CRASH DATA

EJECTION INITIATED no 41% yes 59%	PITCH ATTITUDE	IAS
WRECKAGE RECOVERED 100%	BANK ATTITUDE	MACH
CANOPY/SEAT RECOVERED 100%	IMPACT ANGLE	VVI
		FUEL QUAN.

WRECKAGE	BREAK UP: TOTAL (MANY SMALL PIECES) (NOT RECOGNIZABLE)	MAJOR (MANY MED PIECES) (SOME RECOGNIZABLE)	SIGNIFICANT (SOME LARGE PIECES RECOGNIZABLE)	MINOR (RELATIVELY INTACT)	UNKNOWN	FIRE DAMAGE: TOTAL - MAJOR PUDDLING	MAJOR BURNTHROUGH & SOME PUDDLING	MINOR PAINT BURN/SOOTING	NONE	UNKNOWN
COCKPIT	29%	47%		12%	12%		12%	24%	6%	53%
AVIONICS BAY	47%	24%	6%		24%	6%	12%	24%	12%	47%
EJECT SEAT	6%	12%	24%	35%	24%		12%	6%	35%	47%
CANOPY RAIL		18%	12%	35%	35%		6%	6%	47%	41%
L WING TIP	6%	29%	12%	41%	12%		6%	24%	18%	53%
R WING TIP	12%	24%	24%	29%	12%		12%	18%	18%	53%
VERT TAIL	12%	18%	18%	29%	24%		12%	24%	24%	41%
TAIL CONE	12%	18%	24%	12%	35%		12%	12%	18	4%

ACCIDENT NO.__________ A/C TYPE F-15 PILOT SURVIVED 62%

CATEGORY ACCIDENT__________

CAUSAL FACTORS/CERTAINTY 13 accidents

1	5
2	6
3	7
4	8

PARAMETERS UTILITY (H, M, L)/AVAILABILITY (AVAILABLE, N/A)

TIME	STICK POS 46%	FUEL FLOW 69%
AOA 23%	RUDDER RED POS 31%	OIL PRESS. 8%
ALT (BARO) 69%	ELEV. POS. 54%	A/B POS. 23%
CAS 77%	AILERON POS. 38%	OAT 15%
MACH 8%	RUDDER POS. 31%	ALT (RDR) 8%
PITCH ATT 38%	THROTTLE POS 31%	HYD PRESS 54%
BANK ATT 31%	N_1 62%	UTIL HYD PRES 15
HEADING	N_2 38%	GEN 9%
YAW RATE	EGT 31%	INVERTER
NORM LOAD 38%	CDP 46%	TRIM 15%
FUEL TOT 23%	CADC 15%	MASTER CAUT 92
FUEL/TANK 23%	CAS PITCH 38%	FIRELITE 31%
GEAR POS	ROLL 23%	EPU (APU) 8%
FLAP POS	YAW 15%	STARTER
SB POS	PADDLE SWITCH	FTIT 46%
SLAT POS	ANTI SKID FAIL	
COMM TRANSMIT	NAV STATUS	

CRASH DATA

EJECTION INITIATED yes 69% no 31%	PITCH ATTITUDE	IAS	
WRECKAGE RECOVERED 100%	BANK ATTITUDE	MACH	
CANOPY/SEAT RECOVERED yes 69% unk 8% no 23%	IMPACT ANGLE	VVI	
		FUEL QUAN.	

WRECKAGE	BREAK UP: TOTAL (MANY SMALL PIECES) (NOT RECOGNIZABLE)	MAJOR (MANY MED PIECES) (SOME RECOGNIZABLE)	SIGNIFICANT (SOME LARGE PIECES RECOGNIZABLE)	MINOR (RELATIVELY INTACT)	UNKNOWN	FIRE DAMAGE: TOTAL - MAJOR PUDDLING	MAJOR BURNTHROUGH & SOME PUDDLING	MINOR PAINT BURN/SOOTING	NONE	UNKNOWN
COCKPIT	77%	4%		8%	8%	8%		8%	31%	54%
AVIONICS BAY	77%	8%		8%	8%	8%		8%	31%	54%
EJECT SEAT	23%		15%	31%	31%			8%	77%	15%
CANOPY RAIL	15%	15%	8%	31%	31%			8%	77%	15%
L WING TIP	31%	8%	15%	23%	23%			8%	38%	54%
R WING TIP	15%	8%	8%	46%	23%			8%	54%	38%
VERT TAIL	15%	15%	15%	38%	15%		8%	23%	23%	46%
TAIL CONE	15%		8%	8%	69%		8%	23%	23%	46%

ACCIDENT NO.__________ A/C TYPE F-16 PILOT SURVIVED 100%

CATEGORY ACCIDENT__________ 5 accidents

CAUSAL FACTORS/CERTAINTY

1	5
2	6
3	7
4	8

PARAMETERS UTILITY (H, M, L)/AVAILABILITY (AVAILABLE, N/A)

TIME	STICK POS	FUEL FLOW 80%
AOA	RUDDER RED POS	OIL PRESS. 20%
ALT (BARO) 20%	ELEV. POS.	A/B POS. 20%
CAS 40%	AILERON POS.	OAT
MACH 20%	RUDDER POS.	ALT (RDR) 20%
PITCH ATT 40%	THROTTLE POS 60%	HYD PRESS
BANK ATT 20% ?	N_1 60%	UTIL HYD PRES
HEADING 20%	N_2 80%	GEN
YAW RATE 40%	EGT 60%	INVERTER
NORM LOAD 40%	CDP 20%	TRIM
FUEL TOT 60%	CADC	MASTER CAUT
FUEL/TANK 40%	CAS PITCH –	FIRELITE 20%
GEAR POS	ROLL 40% ?	EPU (APU)
FLAP POS	YAW 20%	STARTER
SB POS	PADDLE SWITCH	Side Slip 20%
SLAT POS	ANTI SKID FAIL	
COMM TRANSMIT	NAV STATUS	
	Roll Rate 20%	
	Pitch Rate 20%	

CRASH DATA

EJECTION INITIATED yes 80%	PITCH ATTITUDE		IAS
WRECKAGE RECOVERED yes 100%	BANK ATTITUDE		MACH
CANOPY/SEAT RECOVERED yes 100%	IMPACT ANGLE		VVI
			FUEL QUAN.

WRECKAGE	BREAK UP: TOTAL (MANY SMALL PIECES) (NOT RECOGNIZABLE)	MAJOR (MANY MED PIECES) (SOME RECOGNIZABLE)	SIGNIFICANT (SOME LARGE PIECES RECOGNIZABLE)	MINOR (RELATIVELY INTACT)	UNKNOWN	FIRE DAMAGE: TOTAL - MAJOR PUDDLING	MAJOR BURNTHROUGH & SOME PUDDLING	MINOR PAINT BURN/SOOTING	NONE	UNKNOWN
COCKPIT	20%	60%	20%				20%	80%		
AVIONICS BAY	20%	60%	20%				20%	60%	20%	
EJECT SEAT				100%					100%	
CANOPY RAIL	20%	60%	20%					20%	80%	
L WING TIP			40%	60%				40%	60%	
R WING TIP			20%	50%				40%	60%	
VERT TAIL				100%				20%	80%	
TAIL CONE			40%	60%				40%	60%	

Minimum F/A-18 Parameters to be Sampled by
Flight Incident Recorder

A) Elapsed Time

B) EGT/TIT (Left and Right Engine)

C) Fuel Flow (Left and Right Main Fuel Flow)

D) RPM (Left and Right NL)

E) RPM (Left and Right NH)

F) Vertical Acceleration (4 Samples per second)

G) Pitch Trim (FCECA or FCECB Takeoff Trim set)

H) Pitch Attitude (Position and Rate)

I) Barometric Altitude

J) Radar Altitude

K) Airspeed (True, Indicated, Mach No.)

L) Roll Attitude (Position and Rate)

M) Elevator Position (Left and Right Stab. Position)

N) Cabin Pressure Warning

O) Generator Warning (Left and Right Generator Out)

P) Flap Position

Q) Oil Quantity Low Warning

R) Fire Warning (Left and Right)

S) Hydraulic Pressure Low Warning (All Hyd References)

T) Auto Flight Control System (on/off)

U) Power Lever Angle Position (Left and Right Engine)

V) Aileron Position

W) Magnetic Heading

X) Rudder Position

Y) Angle of Attack

Z) Cabin Air Temp.

AA) Ambient Temp (OAT)

BB) Nozzle Position (Left and Right Engine)

C I V I L A V I A T I O N A U T H O R I T Y

Airworthiness Division

SPECIFICATION NO. 10

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FLIGHT DATA RECORDER SYSTEMS

CONTENTS

1 INTRODUCTION

1.1 The Air Navigation Order 1972, as amended, requires that certain categories of aeroplanes be equipped with a flight recording system (comprising a flight data recorder system and a cockpit voice recorder system) approved for the purpose by the Civil Aviation Authority.

1.2 Flight data recorder systems installed in aeroplanes in compliance with the Order shall comply with this Specification or with such other specification as the Civil Aviation Authority may approve. Alternative installations submitted for approval shall have at least an equivalent standard of performance and shall comply with the particular requirements of the Order.

1.3 Cockpit Voice Recorder Systems will be subject to compliance with Civil Aviation Authority (Airworthiness Division) Specification No. 11.

2 APPLICABILITY This Specification prescribes the minimum performance standards, the installation requirements and requirements for general accident investigations and maintenance applicable to flight data recorder systems and components installed in conventional sub-sonic aeroplanes in accordance with the provisions of the Air Navigation Order 1972, as amended, Schedule 5, Paragraph 4 (6), Scale S.

3 SYSTEM REQUIREMENTS

3.1 Definition. For the purpose of this Specification the equipment to be approved shall be that which is necessary to a flight data recorder system capable of recording by reference to a time scale, data from which the information required in ANO Schedule 5, Paragraph 4 (6), Scale S can be established.

The flight data recorder system will normally include the following items of equipment:-

(a) One or more units necessary for data acquisition and processing.
(b) A control panel on which system status is displayed.
(c) A crash protected recorder.
(d) Where information is not already available from existing sources transducers to provide a source of data.

3.2 General Flight Data Recorder System Requirements. The primary purpose of the flight data recorder system is the achievement of the three particular objectives of paragraphs 3.2.1(a) to (c). The fourth objective of 3.2.1 (d) is a general one and it can only be achieved to a degree consistent with the number of parameters recorded. Where the recorded data is the same as that which is also presented to the pilots but is obtained from a different source, calibrations shall be available such that the information presented to the pilots in normal flight conditions can be deduced.

3.2.1 Objectives. The objective in the selection of parameters is that the following information, required for accident investigation purposes shall be obtainable either directly or by deduction from the system:-

(a) the flight path of the aeroplane,
(b) the attitude of the aeroplane in achieving that flight path,
(c) the basic forces acting upon the aeroplane and resulting in the achieved flight path (e.g. lift; drag; thrust; control forces), and

(d) the general origin of the basic forces and influences (e.g. navigational information; aeroplane system status information).

3.2.2 Parameters to be Recorded. The recording requirements for conventional sub-sonic aeroplanes shall, in relation to the list in Table 1 be as follows:-

(a)	Aeroplanes having a total maximum weight authorised of between 5700 kg and 11399 kg.	- either a voice recorder or parameters 1 to 9 inclusive.
(b)	Aeroplanes having a total maximum weight authorised of between 11400 kg and 26999 kg	- A voice recorder and parameters 1 to 10 inclusive.
(c)	Aeroplanes having a total maximum weight authorised of 27000 kg and over.	- A voice recorder and parameters 1 to 26 inclusive.

NOTES: (1) It is not intended that the parameter lists resulting from the application of the requirements of 3.2.2 should, in any installation, require more recorder capacity than is provided by a 64 words per second system.

(2) The parameter requirements for non-conventional sub-sonic and for supersonic aeroplanes will be the subject of consultation between the manufacturers, intending operators and the Civil Aviation Authority.

3.3 Accuracy

3.3.1 Long-term Accuracy. The required parameter accuracy is quoted in Table 1 and is, in each case, the RSS (root sum squared) value, measured between the absolute value of the parameter (unless otherwise stated) and the final numerical presentation after read-out.

3.3.2 Repeatability. For any parameter within the range of Table 1 the flight data recorder system (as defined in 3.1) should have a repeatability over a period of one minute in normal flight conditions at least five times better than the parameter accuracy quoted in Table 1.

3.4 Resolution. The resolution of the flight data recorder system over its operating range shall not be less than the short term repeatability specified in 3.3.2.

3.5 Relative Timings. Readings shall be recorded such that relative timings of different parameters can be deduced to within 0·25 seconds.

3.6 Reliability

3.6.1 The flight data recorder system shall be designed with the objective of attaining a mean time between failures consistent with the requirements of 6, and the manufacturer(s) shall recommend in the Maintenance Manual the read-out periods, calibration procedures and overhaul periods necessary to comply with and maintain these standards in service.

3.6.2 In order to achieve compliance with 3.6.1, the design objective for the digital data processing unit and the recorder shall be that not more than one word in 10^4 will be mis-read under the environmental and operating conditions to which the quipment may be subjected in service. As the loss of data synchronism will in the worst case result in the loss of all data for at least one complete data word frame, the probability of its occurrences shall be not greater than one word frame in 10^3 word frames. If parity check is provided then 10 words shown to be spurious by such a parity check may be debited as one mis-read word. As certain digital words may present greater problems in data reconstruction this standard shall be attained at all points in the flight data recorder scale.

3.7 Data Monitor

3.7.1 The flight data recorder system shall include a means of monitoring that valid data is being recorded, and shall present this information on the system control panel which shall be accessible to the flight crew for the preflight check.

3.7.2 An analysis of the monitor to show compliance with 3.7.1 shall be provided by the manufacturer.

3.8 Crash Protected Recorder

3.8.1 Record Duration. The record duration shall be at least 25 hours.

3.8.2 Identification. The crash protected recorder shall be provided with means to facilitate its identification in conditions following a crash including fire. This may be achieved by the recorder being coloured fluorescent orange or international orange and carrying the following warning in relief in black letters at least one inch high:-

Flight recorder - do not open
Enregistreur de vol - ne pas ouvrir

NOTE: Where this method is not appropriate alternative means should be discussed with the Civil Aviation Authority.

3.8.3 Crash Protection Requirements

(a) The warning required by 3.8.2 shall remain legible and the record shall be capable of analysis by normal playback techniques after a flight recorder(s) has been subjected to the following sequence of tests:-

(i) Impact, penetration, crush, fire and fluids, excepting sea water.

(ii) Impact, penetration, crush and sea water.

(b) At the start of the fire tests the recorder shall be at its normal maximum internal working temperature, and shall be allowed to cool naturally after the test.

(c) Test Procedures

(i) Impact. The recorder shall be subjected to half sine wave impact shocks applied to each of the three axes in the most critical direction, and having a peak acceleration of 1,000 'g' for at least 5 milliseconds.

(ii) Penetration Resistance. The recorder shall be subjected to an impact force produced by a 226 kg (500 lb) steel bar which is dropped from a height of 3m (10 ft) on to the weakest face of the recorder in the most critical plane. The point of contact of the bar shall have an area no greater than $32 mm^2$ ($0{\cdot}05 in^2$). The longitudinal axis of the bar shall be vertical at the time of impact.

(iii) Static Crush. The recorder shall be subjected to a static crush force of 22·25 kN (5,000 lbf) applied continuously but not simultaneously to each of the three axes in the most critical direction, for a period of 5 minutes.

(iv) Fire. At least 50% of the outside area of the recorder shall be subjected to flames of at least 1100°C for a period of 30 minutes.

(v) Fluids (excepting seawater). The recording medium shall be immersed for 24 hours in each of the following fluids:-

Aircraft fuel	- J.P.1 (Kerosene) J.P.4
Lubricating Oil	- D.Eng. RD2487
Hydraulic Fluid	- DTD 585, Phosphate ester based fluid
Fire Extinguishing Fluids	- Water glycol + 62% water, CO_2 foam, methyl bromide, freon 12, standard foam liquid, dry powder, CTC, BTM, BCF.

(vi) Sea Water. The recorder or the recording medium shall be immersed in sea water for 30 days.

NOTE: Where the recording medium is immersed in sea water the recorder need not be subjected to the tests specified in 3.8.3 (a) (ii).

3.9 Declarations

3.9.1 General. All the items of equipment which comprise the flight data recorder system shall be designed in accordance with BCAR Sections D, J and R as appropriate and constructed in accordance with the relevant requirements of BS 3G100 Part 1.

Tests shall be carried out to prove compliance with the environmental test requirements of BS 3G100, Part 2 or other Approved Specification, and with the electrical requirements of BS 3G100, Part 3.

3.10 Vibration Tests (Flight Data Recorder). In addition to the requirements of 3.9, it shall be shown either by test or analysis that the recorder will continue to function without loss of data when subjected to vibration conditions corresponding to $\pm$ 1 'g' at 1 Hz for periods of not less than 10 seconds in each of the three major axes.

The recorder shall be tested under the same mounting conditions as declared for the vibration tests called up in 3.9.

3.11 Normal Acceleration Transducer Performance. The damping factor shall be not less than 0·7 of critical damping and the total error in following a single triangular acceleration pulse of 0·5 second duration or greater, shall be no more than 10% of the acceleration. The output/input ratio shall not vary by more than $\pm$ 3dB when the transducer is subjected to a sinusoidal 'g' input within the range of

0 to 4 Hz. Above 4 Hz the output signal shall decrease at not less than 6 dB per octave.

NOTE: It is recommended that at least some of the attenuation is provided in the mechanical design of the transducer, in order to avoid saturation due to noise or high frequency inputs. Attenuation wholly provided by electrical filtering is unlikely to be acceptable.

3.12 Declarations

3.12.1 Equipment. The Applicant for Approval of an item of equipment shall produce a Declaration of Design and Performance in accordance with the requirements of BS 3G100, Part 1. The CAA if satisfied will approve the item in relation to this Declaration. The Declaration shall in addition to that required by BS 3G100, Part 1, contain the following information:-

(a) A statement of the relevant parts of this Specification with which the design complies.

(b) For transducers a statement showing compliance with 3.3 and 3.4 of this Specification.

(c) Any other specification which has a bearing on the design, and the degree of compliance.

(d) Any limitation(s) in the use of the equipment in relation to a flight data recorder system (e.g. mounting attitudes, location, input-output characteristics, interface requirements, etc.).

3.12.2 Systems. The Applicant for Approval of the flight data recorder system shall produce a Declaration of Design and Performance. The CAA if satisfied will approve the system in relation to this Declaration.

The Declaration shall contain, in addition to the information required by BS 3G100, Part 1, Appendix A, the following:-

(a) A list of the equipments (including Approval Numbers if any) which are necessary to the system.

(b) A statement of system accuracy (referred to in Table 1) throughout the environmental range over which the equipments are declared. (A calibration report should be included with the relevant test reports).

(c) A statement of the degree of compliance with the requirements of this Specification (with the relevant test reports).

(d) Confirmation of the availability of read-out facilities capable of complying with the requirements of paragraph 2 of this Specification.

(e) Maintenance procedures necessary to maintain system reliability to the requirements of paragraph 6.

4 INSTALLATION REQUIREMENTS

4.1 General

4.1.1 The flight data recorder system shall be of an approved type and shall be installed in accordance with the appropriate provisions of British Civil Airworthiness Requirements Sections D and J.

The system shall be so installed that in normal working conditions it shall be operating under the environmental conditions to which the items of equipment comprising the system have been declared.

4.1.2 Where the system is connected to mandatory instruments or data sources used for controlling or indicating the flight path of the aeroplane, compliance shall be shown with Chapter D4-1, paragraph 6.

NOTE: Provision of suitable isolation between the instruments or data sources and the flight data recorder system would be an acceptable means of compliance.

4.2 Electrical Supply. The electrical supply to the flight data recorder system shall be of the highest practicable reliability, but need not be taken from the aeroplane's emergency source of supply.

4.3 Operation and Termination

4.3.1 Operation shall be automatically initiated prior to the aeroplane starting to move under its own power, and shall cease at the end of the flight when the aeroplane is no longer capable of moving under its own power.

4.3.2 An automatic means shall be provided to inhibit operation when ground or auxiliary power only is being supplied to the aeroplane.

NOTE: Override facilities may be provided for ground test purposes.

4.4 Synchronisation of Flight Data and Voice Recorders. Where aeroplanes are required to carry both flight data and voice recorders, the pilot's "Press to Transmit" action shall be recorded as an event mark on the flight data recorder, in order to correlate data and voice recordings.

4.5 Normal Acceleration Transducer. The normal accelerometer shall be rigidly attached and located along the longitudinal axis within the permitted centre-of-gravity range of the aeroplane in a manner such that the performance will not be significantly affected by structural modes or vibrations.

4.6 Airspeed and Altitude Data Sources. It is permissible to obtain airspeed and altitude data from either of the pilot's instrument systems. Where the data is obtained from a separate source, this source shall have equivalent integrity and accuracy. Position error information consistent with that required for the pilot's instrument systems shall be provided by the Applicant for Approval.

NOTE: In these circumstances both dimensional and non-dimensional free-air position error correction curves will have to be provided. Data in ground effect for the normal take-off and landing configurations and conditions should also be added. Limits of applicability (e.g. sideslip; reverse thrust; stall proximity) will have to be specified.

4.7 Location

4.7.1 In-so-far as it is practicable, the recorder shall be installed as far to the rear of the aeroplane as possible, consistent with reasonable maintenance access, in a position to minimise the probability of damage from crash impact and subsequent fire.

4.7.2 The recorder shall remain attached to the local structure under normal, longitudinal, and transverse accelerations of 15 'g'.

4.7.3 Where the vibration of the airframe exceeds the limits to which the equipment has been tested at the location in which the recorder is installed, additional vibration testing within the vibration spectrum of that location shall be undertaken to ensure that the recorder will continue to function within its performance specification. In such circumstances the attachments and mounting attitude shall be designed to bring the recorder environment within the declared limits of the equipment.

4.8 System Accuracy. The flight data recorder system shall comply with the accuracy requirements of Table 1. A record shall be provided of an input to output calibration of the system throughout the typical operating range of the required parameters. A read-out of a typical flight shall be provided whose data shall be correlated with that of the pilot instruments, e.g. airspeed, altitude and magnetic heading. The quality of data shall not be less than that required by para. 6.1.1.

5 ACCIDENT INVESTIGATION REQUIREMENTS

5.1 General. In order to ensure a high probability of flight recorded data being readily available for analysis following an accident and to comply with the read-out procedures specified in the Maintenance Schedule, the equipment manufacturer is required to confirm the availability of read-out facilities capable of complying with paragraph 5.2.

5.2 Read-out Requirements. It shall be possible to provide, within 24 hours of receipt of unblemished data:-

(a) a lasting analogue presentation of the recorded parameters (not necessarily including calibration correction) for the entire accident flight in graphical form for visual assessment, and

(b) a print-out of the original data, or calibrated data, in engineering units and decimal form.

NOTE: It is considered that this would normally involve the provision of data on a computer compatible magnetic tape. Continuous manual processing will not be an acceptable means of compliance.

6 REQUIREMENTS FOR RELIABILITY AND MAINTENANCE

6.1 Reliability Requirements. In order to ensure a reasonable probability that data will be available for accident investigation purposes, it is required that, from an adequate and representative sample of all the evidence available from record read-out (i.e. read-out for maintenance and any other purposes), including flights started with a known unserviceable flight data recorder, the aeroplane operator shall show to the satisfaction of the CAA that there is a 92% probability that data is being recorded to a standard which will not significantly degrade the type of analysis which would be carried out in the majority of cases of accident investigation.

6.1.1 Investigation Data Standard. The standard of data available shall be assessed on inspection of the read-out from a completed flight, including a period of cruise at a representative altitude and the periods required by the Air Navigation Order before and after the airborne portion of the flight.

NOTE: For the purposes of the above requirement, a satisfactory standard implies that successive errors and the overall error rate on any or all parameters are sufficiently infrequent. The assessment may be carried out by a simple visual appraisal of an analogue record. Where, however, it is desired to use other methods, or where the results of the visual assessment are doubtful, the following guidelines may be used to indicate a standard which is the minimum likely to be acceptable:-

(1) Isolated significant errors on any parameter should not occur more frequently than once in 20 words of that parameter.

(2) Successive significant errors on any parameter should not occur more frequently than once per 5 minutes, and not for a period longer than 5 seconds.

(3) Loss of data on several or all parameters should not be such that data is lost for more than 8 seconds in any 2 minutes.

(4) The total loss of a single parameter due to a flight data recorder system malfunction should be regarded as a loss of 20% of all information in an eight or nine parameter system. In a full 26 parameter system the total loss of a single parameter should be regarded as a loss of 5% of all information.

6.1.2 Achievement of Reliability Requirement

(a) To demonstrate compliance with 6.1 the aeroplane maintenance schedule shall specify the periodic read-out of the recorded data. The period between read-outs is assessed on the basis of available supplementary checks (e.g. periodic tests by ground test on built-in test equipment, a monitor with a high probability of detecting failure, and on the demonstrated equipment installation reliability standards).

(b) The aeroplane operator shall review periodically the standards being achieved and, in agreement with the CAA, adjust the check periods accordingly, subject to the minimum reliability standards being maintained.

6.2 Calibration. To ensure that the accuracy of data sources is being maintained, these shall be calibrated at intervals to be specified in the aeroplane maintenance schedules. The most recent calibration shall be retained by the aeroplane operator.

To ensure that the overall system performance is maintained an input to output system functional check for a minimum number of representative sources, shall be required at intervals to be specified in the aeroplane maintenance schedule.

6.3 Overhaul. Equipment overhaul periods shall, where appropriate, be specified in the aeroplane Maintenance Schedule.

6.4 Record Retention. The records required to be retained in accordance with the Air Navigation Order shall be in the form of an analogue trace or a digital transcription or the original record.

The time scale shall be such that the data can be read to an accuracy of 1 second or less.

Parameter	Record Interval (Secs) See Note 1	Minimum Range	Accuracy	Remarks
1 Time	1		0·125% hour	GMT or elapsed time
2 Pressure Altitude	1	-305m(-1,000ft) to max. certificated altitude of the aeroplane + 1524m (5,000 ft).	RSS value of scale error test of G.115 and recording and readout error ± 15m (50ft)	
3 Airspeed	1	60 kts to V_{DF} +20 kts	Such that error will not exceed ±3% at speeds at and above the stalling speed of the aeroplane at the maximum landing weight	Accuracy related to pitot minus static pressure
4 Normal Acceleration (ie normal to the longitudinal and lateral axes of the aeroplane)	$\frac{1}{8}$	-3'g' to +6'g'	±0·086'g' measured at each increment of one 'g' from 1 'g' datum (excluding long term datum drift)	See para. 3.11
5 Compass Heading	1	360°	±2°	
6 Gyro Pitch Attitude	$\frac{1}{4}$	±80° or max. pitch angle normally available from the attitude transmitter.	±2° or ±10% of increment from level flight indication, whichever is the greater	
7 Gyro Roll Attitude	$\frac{1}{2}$	±180°	±3° or 10% of increment from level flight indication, whichever is the greater	
8 Engine Power (each engine) EPR or F7 for turbojet aeroplanes. Torque and RPM for propeller driven aeroplanes (Note 2)	One Engine to be sampled each sec. (ie a 4-engined aeroplane will have a particular engine sampled every 4 secs but with a one second stagger between different engines. 3-engined aeroplanes may sample each engine every 4 secs if longitudinal acceleration is being recorded.)	Full Range	Such that thrust can be determined to within ±10% full thrust	

D24/37/13

AD-A101 503 AIRESEARCH MFG CO OF CALIFORNIA TORRANCE F/G 14/3
CRASH SURVIVABLE FLIGHT DATA RECORDING SYSTEM STUDY.(U)
JUN 81 F33615-80-C-0135
UNCLASSIFIED 81-17693 ASD-TR-5011 NL

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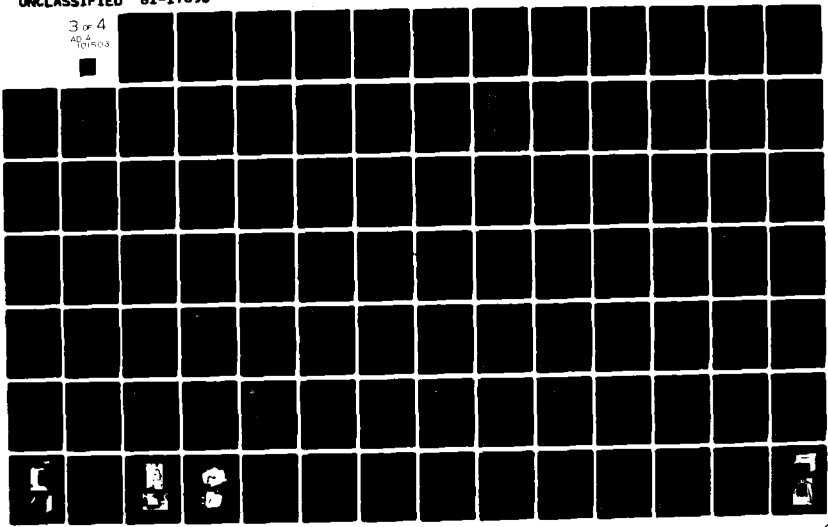

Parameter	Record Interval (Secs) See Note 1	Minimum Range	Accuracy	Remarks
9 Flap Angle (Note 3)	½	Full Range	Such that each gated position is unambiguously determinable from the record	Use of flap selector as data source will not be acceptable
10 "Press to Transmit" Action	1	Event Mark		
11 Lateral Acceleration	¼	±1'g'	±0·02g or ±5% of increment from zero datum, which ever is the greater, (excluding long term datum drift).	
12 Longitudinal Acceleration	1	±1'g'	As for Lateral Acceleration	
13 Reverse (each engine)	4 (1 second stagger)	Event Mark		See parameter 8 re-three engined aeroplanes
14 Leading-edge high lift devices where fitted-position of cockpit control	½	Event Mark		
15 Airbrakes or spoilers where fitted - position of cockpit control	½	Event Mark		
16 Pitch Trim	½	Full Range	±3% of full range	
17 Temperature	2	Covering OAT range of -90°C to +45°C.	Such that indicated OAT can be determined to within ±3°C.	TAT, SAT, OAT etc may be recorded.
18 Undercarriage	2	Event Mark		Indication of "Undercarriage in Transit"
19 Primary flying Controls (Note 4)	¼	Full Range	±½° or 3% of full movement, whichever the greater	Control Surface Position
		Full Range	±3% of Full Range	Control Input Position
		±222N(±50lbf) ±156N(±35lbf) ±666N(±150lbf)	± 44N(±10 lbf) ± 31N(± 7 lbf) ±133N(±30 lbf)	Column Force Wheel Force Pedal Force
20 ILS Localiser Signal	1	±150 micro-amps	±3% of full range	

Parameter	Record Interval (Secs) See Note 1	Minimum Range	Accuracy	Remarks
21 ILS Glideslope Signal	1	±150 micro-amps	±3% of full range	
22 Radio Altitude	1	70m (230 ft) downwards	±0·6m(±2ft) or ±3% of indicated height, whichever is the greater	If provided
23 Essential AC Voltage or frequency	2	30% to 120% of normal value	±5% of normal value (Voltage) ±1% of normal value (Frequency)	Parameter to be selected on basis of value of data
24 Warnings (Note 5)	See Remarks Column	Event Marks		The Record interval of parameters 24, 25 and 26 can be adjusted to suit 4 sec frame
25 Automatic flight control system engagement (Note 6)		Event Marks		
26 Automatic flight control system mode (Note 7)		Event Marks		

NOTES:

(1) The record interval is the maximum time, ±1/64 seconds, between successive samples.

(2) Where auxiliary thrust units are provided it will be acceptable to record an event mark denoting the attainment and removal of a selected high level of power output.

(3) Where gated flap positions are provided and intermediate selections are not possible a record by means of event marks will be acceptable, provided that they are derived from the operating mechanism and not from the flap selector.

(4) Where there are only one or two control surfaces in each plane, measurement should be taken from each surface; where more than two surfaces are provided the measurement should be taken from a common stage (preferably that stage which is closest to the control surfaces) in the control run. "Column/Wheel/Pedal" forces will be an acceptable alternative to control surface deflections providing that the measurements are taken at, or immediately adjacent to, the operating controls. In complex systems it may be necessary, if not already covered by parameter 24, to monitor "Systems Status" in addition to Deflections/Forces.

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(5) Warnings should cover the following:-

Fire (Each Engine and APU)
Cabin Pressurisation
Other Red Light Warnings leading to engine shut down
Fuselage Smoke
Essential Hydraulic/Pneumatic Power.

(6) Autopilot Engagement of each control axis (i.e. Pitch, Roll, Yaw, Autothrottle and Autolift Devices) where these are independently selectable. Basic autopilot engagement to be recorded where axes are not independently selectable.

(7) Selection of each "Capture" or "Acquire" mode, and Autoland, to be recorded together with autoland selection (i.e. Prime Land).

Civil Aviation Authority
Airworthiness Division
Brabazon House
Redhill, Surrey
RH1 1SQ

D24/37/16

APPENDIX B

DATA ON MAXIMUM RATES OF CHANGE OF PARAMETERS FOR THE F-16

<u>**Crash Survivable Flight Data Recorder Study**</u>

For the General Dynamics F16 Aircraft the following information was obtained during our visit to Wright Patterson AFB.

Meetings were held with Melvin Lerass on 20th October and with [illegible] Anders, Stephen Haupt and other personnel from the F16 SPO on the 21st October.

Attached is a list of the parameters with details as supplied by Melvin Lerass. The parameters used for the Signal Data Recorder only are available on [illegible]5% of the aircraft. However, the wiring is provided on all aircraft.

We have requested via Major Schopf a copy of the Interface Control document for this aircraft which provides full details of each of the signals. The aircraft has a Sperry CADC system.

It was suggested that the FDR would best replace the structural integrity monitoring system which is sited aft of the cockpit. In addition to this space [illegible] cu.ft. is available in a similar location.

The tail section, wing tip and tail booms were considered the most survivable areas.

Lear Siegler have a contract for a Flight Control system recorder which records every 64 secs. the status of the flight control system together with a limited number of flight profile parameters, in addition this system records whenever there is a change in a flight control status. Three memory modules are provided, to record in parallel, one is located on the pilots ejection seat, one in a wing tip and the third within the equipment. So far one system has been delivered. The memory modules utilize GI EAROM's.

PARAMETER	SOURCE	TYPE SIGNAL	RANGE	ACCURACY	MAX RATE OF CHANGE	MISSION PROFILE	PRESENT USE
YAW RATE	Flight Control Computer or HUD	DC Analog Serial Digital	[illegible]	5%			Signal Data Recorder Fire Control Radar
SINK RATE (HP)	CADC	3 Wire Ratiometric	±6000ft/min	±30 ft/min or ±(.04 hp - 20)			Autopilot
ELEVATOR POSITION	Horizontal Tail Position Transducers Left & Right	Linear Variable Differential Transformer (LVDT)	0 to ±25.15° 0-6.5 V-Rms (each)	1.5%	60°/sec NO LOAD		Signal Data Recorder
FLAPERON POSITION	Flaperon Position Transducers Left & Right	LVDT	±23° to -20° 0-5.6 V Rms (each)	1.5%	52°/sec NO LOAD		Signal Data Recorder
RUDDER POSITION	Rudder Position Transducers	LVDT	0 to ±30° 0 to 0.25 V Rms	1.5%	120°/sec NO LOAD		Signal Data Recorder
ANGLE OF ATTACK	CADC	Serial Digital	-5 to 40°	±.22°	45°/sec		FCC, HUD
NORMAL LOAD FACTOR	Flight Control Computer	DC Analog 0 to ±2.5 VDC	-7.1g to +12g	0.5%			Signal Data Recorder

PARAMETERS	SOURCE	TYPE SIGNAL	RANGE	ACCURACY	MAX RATE OF CHANGE	MISSION PROFILE	PRESENT USE
RUDDER PEDAL	Rudder Pedal Position Transducer	LVDT	0-6 V Rms 800 Hz	1.5%			Flight Control System
STICK	Stick Force Transducer	LVDT	0-800 MV Rms 800 Hz	5%			Flight Control System
FLAP POSITION	Leading Edge Flap Position Transducer	DC Analog 0-10 VDC	$\pm 2^{\circ}$ to $+25^{\circ}$		30°/sec NO LOAD		Signal Data Recorder
SPEED BRAKE POSITION	Speed Brake Position Switches	28 VDC Discretes at open and closed positions	Closed or Opened				Speed Brake Position Indicator
LANDING GEAR POSITION	Landing Gear Control	DC Discrete 0-30 V	Down $\leq$ 1 Volt Up $\geq$ 24 Volt				Signal Data Recorder
MACH NUMBER	CADC	Serial digital	.1 to 3.0 M	$\pm$.005 to $\pm$.015 M			Avionics
SIDESLIP ANGLE	Fire Control Computer	Serial Digital					HUD

PARAMETER	SOURCE	TYPE SIGNAL	RANGE	ACCURACY	MAX RATE OF CHANGE	MISSION PROFILE	PRESENT USE
HEADING	Inertial Navigation System (INS)	Serial Digital	0-360°	.1°	1 Rad/Sec		Avionics HUD, FCC
PITCH ATTITUDE	INS	Serial Digital	± 180°	.1°	1 Rad/Sec		Avionics HUD, FCC
CALIBRATED AIRSPEED	Central Air Data Computer (CADC)	DC Ratiometric or Serial Digital	75-100 knots 0-10 VDC 50-1000 knots	4 knots (6-.04 Vc):40-100 knots 2kts:VC > 100 kts	44 knots/Sec		Signal Data Recorder Avionics HUD
ALTITUDE	CADC	DC Ratiometric or Serial Digital	-1500 to 80k ft 0-10 VDC -1500 to 80k ft	(200 + .16% hp) 21 ft or .2% hp	78,000 ft/min	0-50,000 ft	Signal Data Recorder Avionics HUD
BANK ANGLE	INS	Serial Digital	±180°	.1°	5.5 Rad/Sec		Avionics HUD, FCC
ROLL RATE	Flight Control Computer or Heads up Display (HUD)	DC Analog or Serial Digital	~~0-140°/sec~~ 5.5 Rad/sec 0-90°/sec	5% ?	20 Rad/Sec^2		Signal Data Recorder Fire Control Radar
PITCH RATE	Flight Control Computer	DC Analog	~~0-45°/sec~~ 1 Rad/sec	5%			Signal Data Recorder

PARAMETERS	SOURCE	TYPE SIGNAL	RANGE	ACCURACY	MAX RATE OF CHANGE	MISSION PROFILE	PRESENT USE
AFTERBURNER NOZZLE POSITION	Nozzle Position Transmitter	Synchro	0-100%	$\pm 2.5^{\circ}$			Nozzle Position Indicator
OIL QUANTITY	NOT AVAILABLE						
GENERATOR OUTPUT	Main & Emergency	115 VAC 400 Hz	MIL-STD-704				
INVERTER OUTPUT	4 Inverters for Flight Control System	26 V 800 Hz					
AIR DATA COMPUTER STATUS	CADC	Serial Digital					
FIRE CONTROL SYSTEM STATUS FCC OPERATIONAL	Fire Control Computer	DC Discrete Non-operational 0-.4 VDC Operational 2.4 VDC min.					

PARAMETERS	SOURCE	TYPE SIGNAL	RANGE	ACCURACY	MAX RATE OF CHANGE	MISSION PROFILE	PRESENT USE
ENGINE RPM N/A	Tachometer Indicator	DC Analog 0-5 VDC	0-100% RPM	.5 to .7%			Signal Data Recorder
ENGINE FTIT	Engine Thermocouple		0-1200°C	2°C			FTIT Indicator
	FTIT Indicator (Planned Modification not presently available)	DC Analog	200-1200°C .72-4.332 VDC	.5 to .7%			Will be used for warning
ENGINE FUEL FLOW	Fuel Flow Transmitter	Synchro	0-80,000 pph	1% of flow rate			Fuel Flow Indicator & IFCC
OIL PRESSURE	Oil Pressure Transmitter	Synchro	0-100 psi	±1.5 psi			Oil Pressure Indicator
HYDRAULIC PRESSURE System A	Hydraulic Pressure Transmitter	Synchro	0-4000 psi	50-75 psi			Hydraulic Pressure Indicator
FUEL QUANTITY	Fuel Quantity System Control Unit	DC Ratiometric	0-20,000 lbs 0-5 VDC	2% of indication plus 2% full scale	86,000 lbs/hr (max. AB at sea level)		Signal Data Recorder
UTILITY HYDRAULIC PRESSURE System B	Hydraulic Pressure Transmitter	Synchro	0-4000 psi	50-75 psi			Hydraulic Pressure Indicator
THROTTLE POSITION	Power Lever Angle Potentiometer	DC	7.75°-57° 0-10 VDC	1-2%			Signal Data Recorder

APPENDIX C

PARAMETER LIST FOR TURBINE ENGINE MONITORING SYSTEM (TEMS) USED ON A LIMITED NUMBER OF A-10'S

Table I
TEMS PARAMETERS

	PARAMETER	SENSOR SIGNAL	
1.	Gas Generator Speed (NG)*	1 cycle/RPM (3.5 V. @1000 RPM, 27 V. @5500 RPM)	ENGINE SENSORS
2.	Fan Speed (NF)	0-5 volts dc, linear with speed	
3.	Power Lever Angle** (PLA)	Synchro, 3 wire, 11.8 volts 400 hz	
4.	Compressor Variable Geometry Position** (VG)	LVDT, 2 wire, 0-13 volts 400 hz synchro	
5.	Interturbine Temperature (ITT)	Ch-Al Thermocouple, ≃ 20 to 40 mv	
6.	Fuel Flow (WF)	0-5 volts dc, after signal conditioning***	
7.	Fuel Pump Discharge Pressure** (PF)	0-5 volts dc	
8.	Compressor Discharge Static Pressure** (PS3)	0-5 volts dc	
9.	Lube System ΔP (PL)	Synchro, 3 wire, 11.8 volts 400 hz	
10.	Accessory Gearbox Vibration** (V1)	Accelerometer, 5 to 4000 hz; record velocity sig. 50 to 600 hz	
11.	Exhaust Frame Vibration** (V2)	Accelerometer, 5 to 4000 hz; record velocity sig. 50 to 600 hz	
12.	Combustion Casing Vibration** (V3)	Accelerometer, 5 to 4000 hz; record velocity sig. 50 to 600 hz	
13.	Master Indicating Chip Detector** (MCD)	Discrete	
14.	Pressure Altitude (ALT)	Synchro, 3 wire, 11.8 volts 400 hz	AIRFRAME SENSORS
15.	Indicated Air Speed (IAS)	Synchro, 3 wire, 11.8 volts 400 hz	
16.	Outside Air Temperature** (OAT)	0-5 volts dc	
17.	Angle of Attack (α)	Synchro, 3 wire, 11.8 volts 400 hz	
18.	Gun Firing Signal	Discrete	
19.	Slats Open/Slats Closed	Discrete	
20.	Aircraft Acceleration - Normal	0-5 volts dc	

* Parenthetical expressions represent parameter symbols as used throughout this report.
**New Transducers
***Signal Conditioner such as G.E. KE88, to be supplied as part of DPU.

APPENDIX D

PARAMETER LIST FOR F-101 CENTRAL INTEGRATED TEST SUBSYSTEM EVALUATION (CITS)

AFWAL-TR-80-2002

F101 CENTRAL INTEGRATED TEST SUBSYSTEM EVALUATION

GENERAL ELECTRIC

FEBRUARY 1980

TECHNICAL REPORT AFWAL-TR-80-2002
FINAL REPORT FOR PERIOD 2 APRIL 1979-31 DECEMBER 1979
APROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT PATTERSON AIR FORCE BASE, OHIO

GARRETT AIRESEARCH MANUFACTURING COMPANY

Table 1. Engine CITS Processor Signals.

Nomenclature	Abbreviation
Fan inlet temperature	T2
Fan rpm	NF
A8 actuator position	A8
Duct pressure ratio	ΔP/P
Inlet guide vane position	BF
Power lever angle	PLA
A8 torque motor current	A8TM
WFR torque motor current	WFRTM
MF torque motor current	MFTM
IGV torque motor current	IGVTM
Augmentor pressure switch position	PAUGSW
Augmentor fuel valve position	WFR/PS3
Compressor discharge pressure	PS3
Augmentor fuel pressure	PWFR
*Flame detector	FDS
Check word A	CWA
Check word B	CWB
Check word C	CWC

Notes: 1. Signals are used for test and isolation mode in flight and on the ground.

2. Signals are serial digital (base 10) and sampled four times per second.

*F101-GE-100 Only

Table 2. Engine Instruments Subsystem Signals.

Nomenclature	Abbreviation
Core rpm	NC
Core fuel flow	CFF
Fan rpm	NF
Fan inlet pressure	PT2
Fan discharge pressure	PT25
Oil pressure	PL
Oil quantity	QL
Oil temperature	TL
Fuel flow	FF
Airframe fuel flow	AFF
Nozzle position	A8
Turbine blade temperature (Note 4)	T4B
Forward vibration	FWDVIB
Forward fan vibration	FWDFVIB
Midvibration	MIDVIB
Midfan vibration	MIDFVIB
Midcore vibration	MIDCVIB
Aft vib	AFTVIB

Notes: 1. Signals are used for test and isolation mode in flight and on the ground.

2. Signals are serial digital (base 10) and sampled four times per second.

3. Signals are acquired by CITS from A/V EMUX.

4. The T5 thermocouple signal is substituted for T4B when engine temperature as measured by the pyrometer is below 700° C.

Table 3. Aircraft Parameter/Information Required for Engine CITS.

Nomenclature	Abbreviation
Anti-ice Switch Position	AISP
Start, Start	ENG STRT
Start, Stop	ENG STOP
Engine Ignition, Continuous Position	---
Engine Ignition, Off Position	---
Speed Lockup	---
Condition Reset	---
Anti-icing System Demand	
Airflow Limit Signal	
Aircraft On-ground Status	
Secondary Power System Status	
Thrust Control Position	
Engine Throttle Control System Error	
Fuel Inlet Temperature	TF
Inlet Control System Status	
Date	
Time	
Aircraft No.	
Engine Serial No.	S/N
Engine Position	E1,E2,E3,E4
LCF Cycles (computed from NF, NC, P_{S3}, and T_{4B})	
Overspeed - Time Versus NF and NC	
Overtemp - Time Versus T_{4B}	
CITS Thrust (calculated)	
Fault Detection/Isolation Output (from engine CITS logic)	

NOTES 1. Signals are acquired by CITS from A/C EMUX.

2. PLA LCF cycles are substituted for P_{S3} LCF cycles on flights after 4-12.

Table 4. CITS Trending Data Requirements.

NF	Fan Speed
NC	Core Speed
AFF	Airframe Fuel Flow
CFF	Core Fuel Flow
T4B	Engine - Temperature
FGC	Calculated Thrust
PT2	Engine Inlet Pressure
T2	Fan Inlet Temperature
PT25	Fan Discharge Pressure
PS3	Compressor Discharge Pressure
A8 (EIS)	Nozzle Area (Engine Instruments)
DP/P	Fan Duct Pressure Ratio
BF	Inlet Guide Vane Angle
FWDVIB	Forward Vibration
FWDFVIB	Forward Fan Vibration
MIDVIB	Midvibration
MIDFVIB	Midfan Vibration
MIDCVIB	Midcore Vibration
AFTVIB	Aft Vibration
PL	Lube Pressure
TL	Lube Temperature
QL	Lube Quantity
AISP	Anti-ice Switch Position
PLA	Power Lever Angle
MO	Mach Number
PS	Static Pressure
CWA	Check Word A
A8TM	Nozzle Actuator Torque Motor Current
MTM	Main Torque Motor Current
WFRTM	Augmentor Fuel Valve Torque Motor Current
BFTM	Fan IGV Torque Motor Current
A8	Nozzle Actuator Position (CITS Processor)
PAUGSW	Augmentor Permission Signal
FDS	Flame Detector Signal
PWFR	Augmentor Fuel Pressure
WFR/PS3	Augmentor Fuel Valve Position
TF	Engine Fuel Inlet Temp
FFLT	CITS Flight/Ground Discrete
LE	ETCS Loop Error Signal
TCL	ETCB Thrust Control Lever Position
REF	ETCS Control Reference Voltage
TFAT	Free Air Stream Temp
S/N	Engine Serial Number
AICD	Anti-ice Command
A/C #	Aircraft Number
POS	Position
DATE	Date
TIME	Time
FLIGHT	Flight
QL/T	Lube Consumption (1)

(1) Calculated rate based on oil added between flights by maintenance.

APPENDIX E

TYPICAL ENGINE MAINTENANCE SYSTEM PARAMETER LIST,
SOCIETY OF AUTOMOTIVE ENGINEERS, INC.

Taken from Technology Review Draft - Aircraft Gas Turbine Engine Monitoring System Guide Society of Automotive Engineers Inc.

FIGURE 10.
TYPICAL EMS PARAMETER LIST

Parameter	Functions						Added for EMS
	Hot Section	Mechanical System	Performance	Control	Tracking	Trending	
Mach No.			X	X	X		
Altitude/Inlet Pressure (P_a/P_t)	X	X	X		X	X	X
Inlet Temp, Total			X	X	X	X	X
EGT (TIT, FTIT, T)	X		X	X	X		
PLA (Pilot Throttle Position)	X				X	X	X
N(HR) (N_2)		X	X	X	X		
N(LR) (N_1)		X	X	X	X		
Fuel Flow (W_f)			X	X	X	X	X
EPR or P			X				
Interstage Compressor Pressure		X	X	X			X
Compressor Discharge Press (P)		X	X	X			X
Interstage Compressor Temperature			X				X
Compressor Discharge Temp (T)			X				X
Vibration (V)		X				X	X
Oil Consumption (Lub Tank Oil Level)		X				X	X
Lube Oil Temp (T_t)		X					
Lube Oil Pressure (P_t) Differential		X					X
Lube Oil Contamination		X				X	
Exhaust Nozzle Position			X	X			
Discretes		X	X		X	X	X
Customer Bleed			X			X	X
Stator Position			X			X	X

Note: Many EMS Parameters Are Available From Existing Aircraft and Engine Sensors. Several Additional Engine Control Status and Engine Parameters Discretes (e.g. Anti-Icing, Weight on Wheels) Can Be Required to Accomplish EMS Functions. To Perform a High Level of Engine Diagnostics and To Provide Increased Troubleshooting Effectiveness, Additional Engine Gas Path and Engine Control System Parameters Be Required. The "Added for EMS" Column Represents Typical Parameters That Can Be Added for an EMS.

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APPENDIX F

FAR'S FOR CRASH PROTECTED FLIGHT RECORDERS AND COCKPIT VOICE RECORDERS code of federal regulations

14

Aeronautics and Space

Revised as of January 1, 1979

CONTAINING
A CODIFICATION OF DOCUMENTS
OF GENERAL APPLICABILITY
AND FUTURE EFFECT

AS OF JANUARY 1, 1979

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the Office of the Federal Register
National Archives and Records Service
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the Federal Register

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Subpart A—General

§ 135.1 Applicability.

(a) Except as provided in paragraph (b) of this section, this part prescribes rules governing—

(1) Air taxi operations conducted under the exemption authority of Part 298 of this title;

(2) The transportation of mail by aircraft conducted under a postal service contract awarded under section 5402c of Title 39, United States Code;

(3) The carrying in air commerce by any person, other than as an air carrier, of persons or property for compensation or hire (commercial operations) in aircraft having a maximum passenger seating configuration, excluding any pilot seat, of 30 seats or less and a maximum payload capacity of 7,500 pounds or less; and

(4) Each person who is on board an aircraft being operated under this part.

(b) This part does not apply to—

(1) Student instruction;

(2) Nonstop sightseeing flights that begin and end at the same airport, and are conducted within a 25 statute mile radius of that airport;

(3) Ferry or training flights;

(4) Aerial work operations, including—

(i) Crop dusting, seeding, spraying, and bird chasing;

(ii) Banner towing;

(iii) Aerial photography or survey;

(iv) Fire fighting;

(v) Helicopter operations in construction or repair work (but not including transportation to and from the site of operations); and

(vi) Powerline or pipeline patrol;

(5) Sightseeing flights conducted in hot air balloons;

(6) Nonstop flights conducted within a 25 statute mile radius of the airport of takeoff carrying persons for the purpose of intentional parachute jumps;

(7) Helicopter flights conducted within a 25 statute mile radius of the airport of takeoff, if—

(i) Not more than two passengers are carried in the helicopter in addition to the required flight crew;

(ii) Each flight is made under VFR during the day;

(iii) The helicopter used is certificated in the standard category and complies with the 100-hour inspection requirements of Part 91 of this chapter;

(iv) The operator notifies the FAA Flight Standards District Office responsible for the geographic area concerned at least 72 hours before each flight and furnishes any essential information that the office requests;

(v) The number of flights does not exceed a total of six in any calendar year;

(vi) Each flight has been approved by the Administrator; and

(vii) Cargo is not carried in or on the helicopter;

(8) Operations conducted under Part 133 or 375 of this title;

(9) Emergency mail service conducted under section 405(h) of the Federal Aviation Act of 1958; or

(10) Carriage of a candidate in a Federal election, an agent of the candidate, or person traveling on behalf of the candidate, if—

(i) The principal business of the person operating the aircraft is not that of an air carrier or commercial operator; and

(ii) The payment for the carriage is required, and does not exceed the amount required to be paid, by regulations of the Federal Election Commission (11 CFR Chapter 1).

The terms "candidate" and "election" have the same meaning as that set forth in the regulations of the Federal Election Commission.

§ 135.2 Air taxi operations with large aircraft.

(a) Except as provided in paragraph (d) of this section, no person may conduct air taxi operations in large aircraft under an individual exemption and authorization issued by the Civil Aeronautics Board or under the exemption authority of Part 298 of this title, unless that person—

(1) Complies with the certification requirements for supplemental air carriers in Part 121 of this chapter, except that the person need not obtain, and that person is not eligible for, a certificate under that part; and

(2) Conducts those operations under the rules of Part 121 of this chapter that apply to supplemental air carriers.

However, the Administrator may issue operations specifications which require an operator to comply with the rules of Part 121 of this chapter that apply to domestic or flag air carriers, as appropriate, in place of the rules required by paragraph (a)(2) of this section, if the Administrator determines compliance with those rules is necessary to provide an appropriate level of safety for the operation.

§ 135.151 Cockpit voice recorders.

(a) No person may operate a turbojet airplane having a passenger seating configuration, excluding any pilot seat, of 10 seats or more, unless it is equipped with an approved cockpit voice recorder that—

(1) Is installed in compliance with Part 25 of this chapter,

(2) Is installed and operated continuously from the use of the check list before the flight to completion of the final check at the end of the flight; and

(3) Has erasure features that may be used so that any time during the operation of the recorder, information recorded more than 30 minutes earlier may be erased or otherwise obliterated.

(b) In the event of an accident, or occurrence requiring immediate notification of the National Transportation Safety Board which results in termination of the flight, the certificate holder shall keep the recorded information for at least 60 days or, if requested by the Administrator or the Board, for a longer period. Information obtained from the record may be used to assist in determining the cause of accidents or occurrences in connection with investigations. The Administrator does not use the record in any civil penalty or certificate action.

§ 135.153 Ground proximity warning system.

No person may operate a turbojet airplane having a passenger seating configuration, excluding any pilot seat, of 10 seats or more, unless it is equipped with—

(a) A ground proximity warning system that meets § 37.201 of this chapter; or

(b) A system that conveys warnings of excessive closure rates with the terrain and any deviations below glide slope by visual and audible means. This system must—

(1) Be approved by the Director, Flight Standards Service; and

(2) Have a means of alerting the pilot when a malfunction occurs in the system.

(c) For the system required by this section, the Airplane Flight Manual shall contain—

(1) Appropriate procedures for—

(i) The use of the equipment;

(ii) Proper flight crew action with respect to the equipment; and

(iii) Deactivation for planned abnormal and emergency conditions; and

(2) An outline of all input sources that must be operating.

(d) No person may deactivate a system required by this section except under procedures in the Airplane Flight Manual.

(e) Whenever a system required by this section is deactivated, an entry shall be made in the airplane maintenance record that includes the date and time of deactivation.

(f) For a system required by paragraph (b) of this section, procedures acceptable to the FAA Flight Standards District Office charged with the overall inspection of the certificate holder shall be established by the certificate holder to ensure that the performance of the system can be appropriately monitored.

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§ 121.343 Flight recorders.

(a) No person may operate a large airplane that is certificated for operations above 25,000 feet altitude or is turbine engine powered, unless it is equipped with one or more approved flight recorders that record data from which the following information may be determined within the ranges, accuracies, and recording intervals specified in Appendix B of this Part—

(1) Time, altitude, airspeed, vertical acceleration, and heading; and

(2) For airplanes having an original type certificate issued after September 30, 1969, pitch attitude, roll attitude, sideslip angle or lateral acceleration, pitch trim position, control column or pitch control surface position, control wheel or lateral control surface position, rudder pedal or yaw control surface position, thrust of each engine, position of each thrust reverser, trailing edge flap or cockpit flap control position, and leading edge flap or cockpit flap control position.

(b) Whenever a flight recorder required by this section is installed, it must be operated continuously from the instant the airplane begins the takeoff roll until it has completed the landing roll at an airport.

(c) Except as provided in paragraph (d) of this section, and except for recorded data erased as authorized in this paragraph, each certificate holder shall keep the recorded data prescribed in paragraph (a) of this section until the airplane has been operated for at least 25 hours of the operating time specified in § 121.359(a). A total of 1 hour of recorded data may be erased for the purpose of testing the flight recorder or the flight recorder system. Any erasure made in accordance with this paragraph must be of the oldest recorded data accumulated at the time of testing. Except as provided in paragraph (d) of this section, no record need be kept more than 60 days.

(d) In the event of an accident or occurrence that requires immediate notification of the National Transportation Safety Board under Part 830 of its regulations and that results in termination of the flight, the certificate holder shall remove the recording media from the airplane and keep the recorded data required by paragraph (a) of this section for at least 60 days and for a longer period upon the request of the Board or the Administrator.

(e) Each flight recorder required by this section must be installed in accordance with the requirements of § 25.1459 of this chapter in effect on August 31, 1977. The correlation required by paragraph (c) of § 25.1459 need be established only on one airplane of any group of airplanes—

(1) That are of the same type,

(2) On which the model flight recorder and its installation are the same; and

(3) On which there is no difference in type design with respect to the installation of those first pilot's instruments associated with the flight recorder. The most recent instrument calibration, including the recording medium from which this calibration is derived, and the recorder correlation, must be retained by each certificate holder.

(f) Each flight recorder required by this section that records the data specified in paragraph (a)(1) of this section must have an approved device to assist in locating that recorder under water.

(g) Each flight recorder required by this section must record data from which the time of each radio transmission either to or from ATC can be determined.

[Amdt. 121-66, 35 FR 13192, Aug. 19, 1970, as amended by Amdt. 121-82, 36 FR 23552, Dec. 10, 1971; Amdt. 121-130, 41 FR 47229, Oct. 28, 1976; Amdt. 121-135, 42 FR 36973, July 18, 1977; Amdt. 121-143, 43 FR 22642, May 25, 1978]

§ 121.359 Cockpit voice recorders.

(a) No certificate holder may operate a large turbine engine powered airplane or a large pressurized airplane with four reciprocating engines unless an approved cockpit voice recorder is installed in that airplane and is operated continuously from the start of the use of the checklist (before starting engines for the purpose of flight), to completion of the final checklist at the termination of the flight.

(b) Each certificate holder shall establish a schedule for completion, before the prescribed dates, of the cockpit voice recorder installations required by paragraph (a) of this section. In addition the certificate holder shall identify any airplane specified in paragraph (a) of this section he intends to discontinue using before the prescribed dates.

(c) The cockpit voice recorder required by this section must meet the following application standards:

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APPENDIX B—AIRCRAFT FLIGHT RECORDER SPECIFICATIONS

Information	Range	Accuracy minimum (recorder and readout)	Recording interval maximum (seconds)
Time		±0.125 percent per hour (except accuracy need not exceed ±4 seconds)	60
Altitude	−1,000 ft to maximum certificated altitude of aircraft	±100 to ±700 ft (see table I, TSO-C51a, PAR section 3.1(c))	1
Airspeed	100 to 450 KIAS or 100 KIAS to 1.2 V_D, whichever is greater	±10 knots at room temp; ±13 knots at low temp (see table II, TSO-C51a, PAR section 3.1(c))	1
Vertical acceleration	−3g to +6g	±0.2g stabilized; ±10 percent transient (see TSO-C51a)	0.25 (or 1 second where peaks recorded)
Heading	360°	±2°	1
Pitch attitude	±75°	±2°	1
Roll attitude	±180°	±2°	1
Lateral acceleration (in lieu of side-slip angle)	±1.0g	±.05g stabilized; ±10 percent transient	0.25 (or 1 second where peaks recorded)
Sideslip angle (in lieu of lateral acceleration)	±90°	±2°	0.5
Pitch trim position	Full range	±1° or ±5 percent whichever is greater	1
Control column or pitch control surface position	Full range	±2°	1
Control wheel or lateral control surface position	Full range	±2°	1
Rudder pedal or yaw control surface position	Full range	±2°	0.5
Thrust of each engine	Full range forward	±2 percent	4
Position of each thrust reverser	Stowed and full reverse		4
Trailing edge flap or cockpit flap control position	Full range (or each discrete position)	±3°	2
Leading edge flap or cockpit flap control position	Each discrete position		2
Angle of attack (if recorded directly)	−20° to +40°	±1	0.5

[Amdt. 121-66, 35 FR 13193, Aug. 19, 1970]

(i) The requirements of Part 25 of this chapter in affect on August 31, 1977.

(2) After September 1, 1980, each recorder container must—

(i) Be either bright orange or bright yellow,

(ii) Have reflective tape affixed to the external surface to facilitate its location under water; and

(iii) Have an approved underwater locating device on or adjacent to the container which is secured in such a manner that they are not likely to be separated during crash impact, unless the cockpit voice recorder, and the flight recorder required by § 121.343, are installed adjacent to each other in such a manner that they are not likely to be separated during crash impact.

(d) In complying with this section, an approved cockpit voice recorder having an erasure feature may be used, so that at any time during the operation of the recorder, information recorded more than 30 minutes earlier may be erased or otherwise obliterated.

(e) In the event of an accident or occurrence requiring immediate notification of the National Transportation Safety Board under Part 830 of its regulations, which results in the termination of the flight, the certificate holder shall keep the recorded information for at least 60 days or, if requested by the Administrator or the Board, for a longer period. Information obtained from the record is used to assist in determining the cause of accidents or occurrences in connection with investigations under Part 830. The Administrator does not use the record in any civil penalty or certificate action.

(Secs. 3, 6, 9, 80 Stat. 931, 49 U.S.C. 1652, 1655, 1657)

[Doc. 6258, 29 FR 19205, Dec. 31, 1964, as amended by Amdt. 121-20, 31 FR 8912, June 28, 1966; Amdt. 121-23, 31 FR 15192, Dec. 3, 1966; Amdt. 121-32, 32 FR 13914, Oct. 6, 1967; Amdt. 121-130, 41 FR 47229, Oct. 28, 1976; Amdt. 121-135, 42 FR 36973, July 18, 1977; Amdt. 121-143, 43 FR 22642, May 25, 1978]

§ 121.360 Ground proximity warning-glide slope deviation alerting system.

(a) Except as provided in paragraphs (b) and (h) of this section, after December 1, 1975, no person may operate a large turbine-powered airplane unless it is equipped with a ground proximity warning system that meets the performance and environmental standards of TSO-C92 or incorporates TSO-approved ground proximity warning equipment.

(b) Ground proximity warning systems approved for use under this Part and installed before June 5, 1975, may be used in lieu of equipment that meets the performance and environmental standards of TSO-C92 or is TSO-approved until January 1, 1977, except that the requirements of paragraph (c) of this section must be met.

(c) For the ground proximity warning system required by this section, the Airplane Flight Manual shall contain—

(1) Appropriate procedures for—

(i) The use of the equipment,

(ii) Proper flight crew action with respect to the equipment;

(iii) Deactivation for planned abnormal and emergency conditions,

(iv) Inhibition of Mode 4 warnings based on flaps being in other than the landing configuration if the system incorporates a Mode 4 flap warning inhibition control; and

(2) An outline of all input sources that must be operating.

(d) After September 1, 1976 (unless required earlier in the certificate holder's operations specifications), no person may deactivate a ground proximity warning system required by this section except in accordance with the procedures contained in the Airplane Flight Manual.

(e) Whenever a ground proximity warning system required by this section is deactivated, an entry shall be made in the airplane maintenance record that includes the date and time of deactivation.

(f) Except as provided in paragraph (g) of this section, after June 1, 1976, no person may operate a large turbine-powered airplane unless it is equipped with a ground proximity warning-glide slope deviation alerting system that meets the performance and environmental standards contained in TSO-C92a, or TSO-C92b or incorporates TSO-approved ground proximity warning-glide slope deviation alerting equipment.

(g) Large turbine-powered airplanes being operated under the provisions of paragraph (b) of this section may be operated until January 1, 1977, without being equipped with the ground proximity warning-glide slope deviation alerting system required by paragraph (f) of this section.

(h) A certificate holder may obtain an extension of the December 1, 1975, compliance date specified in paragraph (a) of this section, but not beyond June 1, 1976, from the Director, Flight Standards Service if, before December 1, 1975—

(1) It shows that due to circumstances beyond its control it cannot comply by that date, and

(2) It has submitted by that date a schedule for compliance, acceptable to the Director, indicating that the system will be installed at the earliest practicable date.

(i) No person may operate a turbojet powered airplane equipped with a system required by paragraph (f) of this section, that incorporates equipment that meets the performance and environmental standards of TSO-C92b or is approved under that TSO, using other than Warning Envelopes 1 or 2 for Warning Modes 1 and 4.

[Amdt. 121-119, 40 FR 19638, May 6, 1975, as amended by Amdt. 121-122, 40 FR 4218…, Sept. 11, 1975; Amdt. 121-125, 40 FR 507…, Oct. 31, 1975; Amdt. 121-126, 40 FR 553…, Nov. 28, 1975; Amdt. 121-129, 41 FR 3507…, Aug. 10, 1976]

§ 25.1457 Cockpit voice recorders.

(a) Each cockpit voice recorder required by the operating rules of this chapter must be approved and must be installed so that it will record the following:

(1) Voice communications transmitted from or received in the airplane by radio.

(2) Voice communications of flight crewmembers on the flight deck.

(3) Voice communications of flight crewmembers on the flight deck, using the airplane's interphone system.

(4) Voice or audio signals identifying navigation or approach aids introduced into a headset or speaker.

(5) Voice communications of flight crewmembers using the passenger loudspeaker system, if there is such a system and if the fourth channel is available in accordance with the requirements of paragraph (c)(4)(ii) of this section.

(b) The recording requirements of paragraph (a)(2) of this section must be met by installing a cockpit-mounted area microphone, located in the best position for recording voice communications originating at the first and second pilot stations and voice communications of other crewmembers on the flight deck when directed to those stations. The microphone must be so located and, if necessary, the preamplifiers and filters of the recorder must be so adjusted or supplemented that the intelligibility of the recorded communications is as high as practicable when recorded under flight cockpit noise conditions and played back. Repeated aural or visual playback of the record may be used in evaluating intelligibility.

(c) Each cockpit voice recorder must be installed so that the part of the communication or audio signals specified in paragraph (a) of this section obtained from each of the following sources is recorded on a separate channel:

(1) For the first channel, from each microphone, headset, or speaker used at the first pilot station.

(2) For the second channel, from each microphone, headset, or speaker used at the second pilot station.

(3) For the third channel—from the cockpit-mounted area microphone.

(4) For the fourth channel, from—

(i) Each microphone, headset, or speaker used at the stations for the third and fourth crewmembers; or

(ii) If the stations specified in paragraph (c)(4)(i) of this section are not required or if the signal at such a station is picked up by another channel, each microphone on the flight deck that is used with the passenger loudspeaker system, if its signals are not picked up by another channel.

(d) Each cockpit voice recorder must be installed so that—

(1) It receives its electric power from the bus that provides the maximum reliability for operation of the cockpit voice recorder without jeopardizing service to essential or emergency loads.

(2) There is an automatic means to simultaneously stop the recorder and prevent each erasure feature from functioning, within 10 minutes after crash impact; and

(3) There is an aural or visual means for preflight checking of the recorder for proper operation.

(e) The record container must be located and mounted to minimize the probability of rupture of the container as a result of crash impact and consequent heat damage to the record from fire. In meeting this requirement, the record container must be as far aft as practicable, but may not be where aft mounted engines may crush the container during impact. However, it need not be outside of the pressurized compartment.

(f) If the cockpit voice recorder has a bulk erasure device, the installation must be designed to minimize the probability of inadvertent operation and actuation of the device during crash impact.

(g) Each recorder container must—

(1) Be either bright orange or bright yellow;

(2) Have reflective tape affixed to its external surface to facilitate its location under water; and

(3) Have an underwater locating device, when required by the operating rules of this chapter, on or adjacent to the container which is secured in such manner that they are not likely to be separated during crash impact.

(Secs. 313(a), 601, 603, 604, and 605 of the Federal Aviation Act of 1958 (49 U.S.C. 1354(a), 1421, 1423, 1424, and 1425), and sec. 6(c) of the Department of Transportation Act (49 U.S.C. 1655(c)))

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-2, 30 FR 3932, Mar. 26, 1965; Amdt. 25-16, 32 FR 13914, Oct. 6, 1967; Amdt. 25-41, 42 FR 36971, July 18, 1977]

§ 25.1459 Flight recorders.

(a) Each flight recorder required by the operating rules of this chapter must be installed so that—

(1) It is supplied with airspeed, altitude, and directional data obtained from sources that meet the accuracy requirements of §§ 25.1323, 25.1325, and 25.1327, as appropriate;

(2) The vertical acceleration sensor is rigidly attached, and located longitudinally either within the approved center of gravity limits of the airplane, or at a distance forward or aft of these limits that does not exceed 25 percent of the airplane's mean aerodynamic chord;

(3) It receives its electrical power from the bus that provides the maximum reliability for operation of the flight recorder without jeopardizing service to essential or emergency loads;

(4) There is an aural or visual means for preflight checking of the recorder for proper recorder tape movement;

(5) Except for recorders powered solely by the engine-driven electrical generator system, there is an automatic means to simultaneously stop a recorder that has a data erasure feature and prevent each erasure feature from functioning, within 10 minutes after crash impact; and

(6) There is a means to record data from which the time of each radio transmission either to or from ATC can be determined.

(b) Each nonejectable record container must be located and mounted so as to minimize the probability of container rupture resulting from crash impact and subsequent damage to the record from fire. In meeting this requirement the record container must be located as far aft as practicable, but need not be aft of the pressurized compartment, and may not be where aft-mounted engines may crush the container upon impact.

(c) A correlation must be established between the flight recorder readings of airspeed, altitude, and heading and the corresponding readings (taking into account correction factors) of the first pilot's instruments. The correlation must cover the airspeed range over which the airplane is to be operated, the range of altitude to which the airplane is limited, and 360 degrees of heading. Correlation may be established on the ground as appropriate.

(d) Each recorder container must—

(1) Be either bright orange or bright yellow;

(2) Have reflective tape affixed to its external surface to facilitate its location under water; and

(3) Have an underwater locating device, when required by the operating rules of this chapter, on or adjacent to the container which is secured in such a manner that they are not likely to be separated during crash impact.

(Secs. 313(a), 601, 603, 604, and 605 of the Federal Aviation Act of 1958 (49 U.S.C. 1354(a), 1421, 1423, 1424, and 1425), and sec. 6(c) of the Department of Transportation Act (49 U.S.C. 1655(c)))

[Amdt. 25-8, 31 FR 127, Jan. 6, 1966, as amended by Amdt. 25-25, 35 FR 13192, Aug. 19, 1970; Amdt. 25-37, 40 FR 2577, Jan. 14, 1975; Amdt. 25-41, 42 FR 36971, July 18, 1977]

§ 37.150 Aircraft flight recorder—TSO-C51a.

(a) *Applicability.* This technical standard order prescribes minimum performance standards that aircraft flight recorders must meet in order to be identified with the applicable TSO marking. New models of flight recorders that are to be identified and that are manufactured on or after the effective date of this section must meet the Minimum Performance Standard for Aircraft Flight Recorders set forth at the end of this section.

(b) *Marking.* In addition to the markings required by § 37.7, the rating (nominal voltage and wattage) must also be marked on the recorder.

(c) *Data requirements.* The manufacturer must furnish the Chief, Engineering and Manufacturing Branch (in the case of the Western Region, the Chief, Aircraft Engineering Division), Flight Standards Division, Federal Aviation Administration, in the region where the manufacturer is located, the following technical data:

(1) Six copies of the manufacturer's operating instructions, equipment limitations, and installation procedures.

(2) One copy of the manufacturer's test report.

Minimum Performance Standard for Aircraft Flight Recorder

1. *Purpose.* To establish minimum requirements for approved Aircraft Flight Recorders to be used in aircraft primarily for accident analysis, the operation of which may subject the recorder to environmental conditions specified in section 3.

2. *Scope.* This standard covers three basic types of aircraft flight recorders for recording time, air speed, altitude, vertical acceleration, and heading. The intelligence received by the record medium can be from direct and/or remote sensors.

2.1 *Definition of the types.* Type I—Nonejectable. Type II—Nonejectable, restricted to any location more than one-half of the wing root chord from the main wing structure through the fuselage and from any fuel tanks. Type III—Ejectable, unrestricted location.

3. *General requirements.*

3.1 *Environmental conditions.* The following conditions have been established as design requirements only. Tests shall be conducted as specified in sections 5, 6, and 7.

3.1.1 *Temperature.* When installed in accordance with the instrument manufacturer's instructions, the recorder shall function over the range of ambient temperature shown in column A below and shall not be adversely affected by exposure to the range of temperature shown in column B below.

Instrument location	A	B
Heated areas (temperature controlled)	30 to 50C	65 to 70C
Unheated areas (temperature uncontrolled)	55 to 70C	65 to 70C

3.1.2 *Humidity.* The recorder shall function and shall not be adversely affected when exposed to any relative humidity in the range from 0 to 95 percent at a temperature of approximately 32° C.

3.1.3 *Vibration.* When installed in accordance with the instrument manufacturer's instructions, the recorder shall function properly and shall not be adversely affected when subjected to vibrations of the following characteristics

Recorder location in airframe	Cycles per sec.	Max double amplitude (inches)	Max acceleration
Airframe structure mounted	5-500	[illegible]	10g

3.1.4 *Altitude.* The recorder shall function and shall not be adversely affected when subjected to a pressure and temperature range equivalent to −1,000 to 50,000 feet standard altitude, per NACA Report No 1235, except as limited by the application of paragraph 3.1.1. The recorder shall not be adversely affected following exposure to extremes in ambient pressures of 50 and 3 in. Hg absolute.

3.1.5 *Radio interference.* The recorder shall not be the source of objectionable interference, under operating conditions at any frequencies used on aircraft, either by radiation or feedback, in electronic equipment installed in the same aircraft as the recorder.

3.1.6 *Magnetic effect.* The magnetic effect of the recorder shall not adversely affect the operation of the other instruments installed in the same aircraft.

4. *Detail requirements.*

4.1 *Recording medium.* The record medium shall conform to the following requirements:

a. The recording medium of recorders employing mechanical inscribed markings shall advance at a rate of not less than 6 inches per hour, and that of recorders employing other means of recording shall advance at a rate sufficient to permit resolution within the accuracy prescribed in section 4.3.

b. The recording medium shall provide a recording of the required data for at least the total elapsed operating time of a flight for which the aircraft might be used.

c. The recording medium shall not be subject to deterioration or distortion of the recorded data within the limits specified herein.

4.2 *Recording intervals and ranges.*

a. Time: The time lapse shall be recorded at intervals of not more than 1 minute.

b. Pressure altitude: −1,000 to 50,000 feet of standard atmosphere pressures, and shall be recorded at intervals of not more than one second.

c. Vertical acceleration: +6 to −3g, and shall be recorded at intervals of not more than ⅒ of 1 second, or at intervals of 1 second in which peak accelerations are recorded.

d. Air speed: 100 to 450 knots IAS, and shall be recorded at intervals of not more than one second.

e. Heading: 360 degrees azimuth, and shall be recorded at intervals of not more than one second.

4.3 *Record resolution.* The record resolution shall be such that the data can be analyzed with the accuracy specified in section 6.

4.4 *Record protection.* The recorder shall be of such design that the recorded data will be protected against damage by fire, impact, and water within the limits specified herein.

4.5 *Pressure altitude.* The terms of pressure altitude shall conform to tables I and II.

4.6 *Air speed.* The terms of air speed shall conform to table III.

4.7 *Power variations.* All units shall properly function with +10 percent to −20 percent variation in DC voltage and/or ±10 percent variation in a.c. voltage and ±5 percent in frequency, provided the a.c. voltage and frequency vary in the same direction. The recorder shall not be damaged when subjected to lower voltages.

4.8 *Power malfunction indication.* A means shall be provided for indicating when adequate power is not being received by the recorder for proper operation.

4.9 *Automatic ejection.* The automatic ejection provision of Type III recorders, including the structure holding the ejectable portion, shall be capable of operating when subjected to inertia loads corresponding to an acceleration of 6g's acting in any direction.

5. *Test conditions.*

5.1 *Atmospheric conditions.* Unless otherwise specified all tests required by this standard shall be conducted at an atmospheric pressure of approximately 29.92 inches of mercury and at an ambient temperature of approximately 25° C. When tests are conducted with the atmospheric pressure or the temperature substantially different from these values, allowance shall be made for the variation from the specified conditions.

5.2 *Vibration (to minimize friction).* Unless otherwise specified all tests for performance may be made with the recorder subjected to a vibration of 0.002 to 0.005 inch double amplitude at a frequency of 1,500 to 2,000 cycles per minute. The term double amplitude as used herein indicates total displacement from positive maximum to negative maximum.

5.3 *Vibration equipment.* Vibration equipment shall be used which will provide frequencies and amplitudes consistent with the requirements of section 3.1.3 with the following characteristics:

5.3.1 *Linear motion vibration.* Vibration equipment for testing airframe structure-mounted recorders of portions thereof shall be such as to allow vibration to be applied along each of three mutually perpendicular axes of the test specimen.

5.3.2 *Circular motion vibration.* Vibration equipment for testing shock-mounted recorders of portions thereof shall be such that a point on the case will describe, in a plane inclined 45 degrees to the horizontal plane, a circle, the diameter of which is equal to the double amplitude.

5.4 *Position.* All tests shall be conducted with the recorder mounted in its normal operating position.

5.5 *Test voltage.* All tests for performance shall be conducted at the voltage rating recommended by the manufacturer.

5.6 *Power conditions.* All tests for performance shall be conducted at the power rating recommended by the manufacturer.

6. *Allowable record errors.*

6.1 *Altitude record error.* The recorder shall be tested for allowable error at the test points specified in table I on decreasing and increasing pressure. The rate of change in pressure during this test shall not be less than 3,000 feet per minute. On decreasing pressure, the pressure shall be brought down to, but shall not exceed, the specified test point. On increasing pressure, the pressure shall be brought up to, but shall not exceed, the specified test point. Within 1 minute after applying the specified pressure, the error in the record shall not exceed the tolerance values indicated in table I for each test point.

6.2 *Acceleration record error.* The acceleration error shall not exceed plus or minus 0.2G in a stabilized condition, and the total error in following a single, triangular, acceleration pulse of one-half second duration or greater, shall be no more than 10 percent of the acceleration. (An analytical evaluation is considered acceptable.)

6.3 *Time scale record error.* The time lapse error shall not exceed plus or minus 1.0 percent during an 8-hour period.

6.4 *Air speed record error.* The recorder shall be tested for allowable error at the test points specified in table III on increasing and decreasing speeds. The allowable error shall not exceed the tolerance value specified in table III.

6.5 *Heading record error.* The heading record error shall not exceed plus or minus 2 degrees when measured at 15 degree intervals over 360 degrees in azimuth. This error is the difference between the sensor and the recorder.

7. *Performance tests.* The following tests in addition to any others deemed necessary by the manufacturer, shall be the basis for determining compliance with the performance requirements of this standard.

7.1 *Room temperature.* The recorder shall be tested at room temperature to determine compliance with the requirements under Section 6.

7.2 *Low temperature.* The recorder shall be subjected to an ambient temperature of minus 55° C for 5 hours and while still exposed to this temperature it shall be tested to determine compliance with the requirements under section 6.

7.3 *High temperature.* The recorder shall be subjected to an ambient temperature of 60° C. for 5 hours and while still exposed to this temperature it shall be tested to determine compliance with the room temperature accuracies under section 6.

7.4 *Extreme temperature exposure.* The recorder, after exposure to an ambient temperature of 70° C. for 24 hours followed by exposure to −65° C. for 24 hours followed immediately by exposure to room temperature for not more than 3 hours, shall meet the requirements of section 7.1. There shall be no evidence of damage as a result of exposure to the extreme temperatures.

7.5 *Hysteresis.* Not more than 15 minutes after the altitude sensor has been first subjected to the pressure corresponding to standard altitude of 50,000 feet, the pressure shall be increased at a rate corresponding to a decrease in altitude of not less than 3,000 feet per minute until the pressure corresponding to 25,000 is reached. Within 1[illegible] seconds the error shall not exceed the room temperature error at this test point by more than 100 feet. The altitude sensor shall remain at this pressure for not more than 15 minutes before the test to determine compliance with table II is made after which the pressure shall be further increased at the above rate until the pressure corresponding to 20,000 feet is reached. The altitude sensor shall remain at this pressure for not more than 10 minutes before the test to determine compliance with table II is made. The pressure shall be further increased at the above rate until atmospheric pressure is reached.

7.6 *After effect.* Not more than 5 minutes after the completion of the hysteresis test the altitude record shall have returned to its original recording, corrected for any change in atmospheric pressure, within the tolerance shown in table II.

7.7 *Vibration.*

7.7.1 *Resonance.* The recorder, while operating, shall be subjected to a resonant frequency survey of the appropriate range specified in section 3.1.3 in order to determine if there exists any resonant frequencies of the parts. The amplitude used may be any convenient value that does not exceed the maximum double amplitude and the maximum acceleration specified in section 3.1.3.

The recorder shall then be subjected to a vibration at the appropriate maximum double amplitude or maximum acceleration specified in section 3.1.3 at the resonant frequency for a period of 1 hour in each axis or with circular motion vibration, whichever is applicable. When more than one resonant frequency is encountered with vibration applied along any one axis, a test period may be accomplished at the most severe resonance, or the period may be divided among the resonant frequencies, whichever shall be considered most likely to produce failure. The test period shall not be less than one-half hour at any resonant mode. When resonant frequencies are not apparent within the specified frequency range the recorder shall be vibrated for 2 hours in accordance with the vibration requirements of section 3.1.3 at the maximum double amplitude and the frequency to provide the maximum acceleration.

7.7.2 *Cycling.* The recorder, while operating, shall be tested with the frequency cycled between limits specified in section 3.1.3 in 15-minute cycles for a period of 1 hour in each axis at an applied double amplitude specified in section 3.1.3 or an acceleration specified in section 3.1.3, whichever is the limiting value. After the completion of this vibration test, no damage shall be evident and the recorder shall meet the requirements of section 6.

7.8 *Humidity, water, impact, penetration resistance, static crush, and fire protection tests.* The humidity, impact, penetration resistance, static crush, and fire protection tests shall be made in the following sequence on the same recorder without the need for repairs.

7.8.1 *Humidity.* The recorder shall be mounted in a chamber maintained at a temperature of 70±2° C. and a relative humidity of 95±5 percent for a period of 6 hours. After this period the heat should be shut off and the recorder should be allowed to cool for a period of 18 hours in this atmosphere in which the humidity rises to 100 percent as the temperature decreases to not more than 38° C. This complete cycle should be conducted fifteen (15) times. Immediately after cycling, the recorder shall be subjected to the Record Error Tests of section 6.

7.8.2 *Impact.* The intelligence on the record medium shall be capable of being analyzed after the recorder has been subjected to the following impact shock. Types I and II—Half sine wave impact shocks applied to each of the three main orthogonal axes and having a peak acceleration magnitude of 1,000 g with a time duration of at least 5 milliseconds. Type III—Acceleration not less than the shocks developed on contact with a horizontal rock surface, considering the direction of ejection and any provisions for alleviation of shock. With regard to the former, the aircraft shall be assumed to be tilted at least 30 degrees from horizontal in the most critical direction.

7.8.3 *Penetration resistance (Type I and II recorders only).* The intelligence on the record medium shall be capable of being analyzed after the recorder has been subjected to an impact force equal to a 500-pound steel bar which is dropped from a height of 10 feet to strike each side of the enclosure in the most critical plane. The point of contact of the bar shall have an area that is no greater than 0.05 square inches. The longitudinal axis of the bar shall be vertical at the time of impact. NOTE: The objective of this test is to achieve protection of the record medium from possible damage caused by airframe structural members striking the recorder case during crash impact.

7.8.4 *Static crush (Type I and II recorders only).* The intelligence on the record medium shall be capable of being analyzed after the recorder has been subjected to a static crush force of 5,000 pounds applied continuously but not simultaneously to each of the three main orthogonal axes for a test period of 5 minutes.

7.8.5 *Fire protection.* The record medium shall remain intact so that the intelligence can be analyzed after the recorder is exposed to flames of 1100° C enveloping at least 50 percent of the outside area of the case for the following periods of time: Type I—30 minutes. Type II—15 minutes. Type III—1.5 minutes.

7.8.6 *Water protection.* The intelligence on the record medium shall be capable of remaining permanent and reproducible after the record medium has been immersed in seawater for 36 hours.

7.9 *Position error.* The recorder shall meet the following requirements when turned from its normal operating position through 90° forward and back, and left and right, where applicable:

a. Time. Section 6.3.

b. Altitude. Section 6.1, except that the tolerance may be increased by 25 feet.

c. Acceleration. Section 6.2.

d. Air speed. Section 6.4.

e. Heading. Section 6.5.

7.10 *Dielectric.* The insulation shall be subjected to a dielectric test with an RMS voltage at a commercial frequency applied for a period of 5 seconds, equivalent to five times normal circuit operating voltage, except where circuits include components for which such a test would be inappropriate, the test voltage shall be 1.25 times normal circuit operating voltage. The insulation resistance shall not be less than 20 megohms at that voltage.

7.11 *Automatic ejection means.* The automatic ejection means for Type III recorders shall be tested to demonstrate that it is capable of ejecting the recorder from its mounting when subjected to forward acting inertia loads of 5g's to 6g's.

8.0 *Recorder color.* The exterior surface of the recorder must be finished in either a bright orange or a bright yellow color.

TABLE I—ALTITUDE RECORD ERROR TABLE

Standard altitude (feet)	Equivalent pressure mercury MM	Equivalent pressure mercury IN. HG	Tolerance, feet plus or minus: Room temp. sec. 6.1	Tolerance, feet plus or minus: Low temp. sec. 7.1
-1,000	787.9	31.02	100	150
-500	773.8	30.47	100	———
0	760.0	29.92	100	150
500	746.4	29.38	100	———
1,000	732.9	28.86	100	———
1,500	719.7	28.33	100	———
2,000	706.6	27.82	100	———
3,000	681.1	26.81	125	———
4,000	656.3	25.84	150	210
6,000	609.0	23.98	180	250
8,000	564.4	22.22	180	———
10,000	522.6	20.58	190	———
12,000	483.3	19.03	190	260
14,000	446.4	17.57	210	———
16,000	411.8	16.21	240	———
18,000	379.4	14.94	270	400
20,000	349.1	13.75	300	———
22,000	320.8	12.63	335	———
25,000	281.9	11.10	375	500
30,000	225.6	8.88	450	600
35,000	178.7	7.04	525	750
40,000	140.7	5.54	600	900
50,000	87.3	3.44	700	———

TABLE II—ALTITUDE TEST TABLE

Tests	Reference section	Tolerance ft.
Hysteresis	7.4	———
First test point 25,000 ———	———	*
Second test point 20,000 ———	———	*
After effect test ———	7.5	[illegible]

*In excess of the room temperature error.

TABLE III—AIRSPEED RECORD ERROR TABLE

Standard airspeed (knots)	Tolerance knots plus or minus: Room temp. sec. 6.1	Tolerance knots plus or minus: Low temp. sec. 7.1
100	10	12
150	10	12
200	10	12
250	10	12
300	10	12
350	10	12
400	10	12
450	10	12

(Amdt. 37-5, 31 FR 127, Jan. 6, 1966, as amended by Doc. No. 8084, 32 FR 5769, Apr. 11, 1967.)

§ 37.150 Cockpit voice recorder—TSO-C[illegible]

(a) *Applicability.* (1) Minimum performance standards are hereby established for cockpit voice recorders for use on United States civil aircraft. New models of cockpit voice recorders manufactured for use on civil aircraft on or after September 2, 1964 shall meet the standards specified in Federal Aviation Administration Standard "Minimum Performance Standards, Cockpit Voice Recorders," dated November 1, 1963,¹ and Federal Aviation Administration document entitled "Environmental Test Procedures for Airborne Electronic Equipment," dated August 31, 1963,¹ except as provided in paragraph (a)(2) of this section.

(2) Federal Aviation Administration document, "Environmental Test Procedures for Airborne Electronic Equipment," outlines various test procedures which define the environmental extremes over which the equipment shall be designed to operate. Some test procedures have categories established and some do not. Where categories are established, only equipment which qualifies under one or more of the following categories, as specified in the FAA document, is elegible for approval under this order:

(i) Temperature-Altitude Test—Categories A, B, C, or D.

(ii) Vibration Test—Categories A, B, C, D, E, or F.

(iii) Audio-Frequency Magnetic Field Susceptibility Test—Categories A or B.

(iv) Radio-Frequency Susceptibility Test—Category A, and

(v) Emission of Spurious Radio-Frequency Energy Test—Category A.

(b) *Marking* (1) In addition to the markings specified in § 37.7(d), the equipment shall be marked to indicate the environmental extremes over which it has been designed to operate. There are six environmental test procedures outlined in the FAA document, "Environmental Test Procedures for Airborne Electronic Equipment," which have categories established. These shall be identified on the nameplate by the words "environmental categories" or, as abbreviated "Env. Cat." followed by six letters which identify the categories under which the equipment is qualified. Reading from left to right, the category designations shall appear on the nameplate in the following order so that they may be readily identified.

(i) Temperature-Altitude Category;

(ii) Vibration Test Category;

(iii) Audio-Frequency Magnetic Field Susceptibility Test Category,

(iv) Radio-Frequency Susceptibility Test Category;

(v) Emission of Spurious Radio-Frequency Energy Test Category; and

(vi) Explosion Test.

(2) Equipment which meets the explosion test requirement shall be identified by the letter "E". Equipment which does not meet the explosion test requirement shall be identified by the letter "X". A typical nameplate identification would be as follows: Env. Cat. DBAAAX.

(3) In some cases such as under the Temperature-Altitude Test Category, a manufacturer may wish to substantiate his equipment under two categories. In this case, the nameplate shall be marked with both categories in the space designated for that category by placing one letter above the other in the following manner:

A
Env. Cat. D BAAAX.

(c) *Data requirements.* In accordance the with the provisions of § 37.5, the manufacturer shall furnish to the Chief, Engineering and Manufacturing Branch, Flight Standards Division, Federal Aviation Administration, in the region in which the manufacturer is located the following technical data.

(1) Six copies of the manufacturer's operating instructions and equipment limitations.

(2) Six copies of the installation procedures with applicable schematic drawings, wiring diagrams, and specifications, indicating any limitations, restrictions, or other conditions pertinent to installation, and

(3) One copy of the manufacturer's test report.

[Doc. No 5065, 29 FR 16317, Nov. 17, 1964, as amended by Doc. No 8084, 32 FR 5769, Apr. 11, 1967]

[1]Copies may be obtained upon request addressed to the Federal Aviation Administration, Attention HQ-430, Washington, D.C. 20553

§ 91.35 Flight recorders and cockpit voice recorders.

No holder of an air carrier or commercial operator certificate may conduct any operation under this part with an aircraft listed in his operations specifications or current list of aircraft used in air transportation unless that aircraft complies with any applicable flight recorder and cockpit voice recorder requirements of the part under which its certificate is issued, except that it may—

(a) Ferry an aircraft with an inoperative flight recorder or cockpit voice recorder from a place where repair or replacement cannot be made to a place where they can be made

(b) Continue a flight as originally planned, if the flight recorder or cockpit voice recorder becomes inoperative after the aircraft has taken off.

(c) Conduct an airworthiness flight test, during which the flight recorder or cockpit voice recorder is turned off to test it or to test any communications or electrical equipment installed in the aircraft; or

(d) Ferry a newly acquired aircraft from the place where possession of it was taken to a place where the flight recorder or cockpit voice recorder is to be installed

(49 U.S.C. 1423, 1424)

[Amdt. 91-4, 29 FR 8404, July 8, 1964, as amended by Amdt. 91-77, 35 FR 7293, May 9, 1970]

APPENDIX G

VISIT REPORTS

APPENDIX G

VISIT REPORTS

A list of the visit reports used in this study is as follows:

(a) Wright Patterson Air Force Base and Fairchild Republic Co., re. A-10

(b) Wright Patterson Air Force Base, re. F-15

(c) Wright Patterson Air Force Base, re. F-16 (included as Appendix B)

(d) Naval Air Test Centre - Patuxent River (2 visits)

(e) Norton Air Force Base

(f) NAVAIR Systems Command

(g) NTSB Washington

(h) Report of actions and progress 16 Oct to 1 Nov 1980

(i) United Kingdom Accident Investigation Branch, Farnborough, U.K.

(j) British Airways - Engineering, Heathron

(k) Royal Aircraft Establishment Structures Dept., Farnborough, U.K.

(l) EASAMS Ltd., Camberly, U.K.

(m) U.K. Civil Aviation Authority, Redhill, U.K.

(n) U.K. Ministry of Defense, Inspectorate of Flight Safety, London

The following information regarding the A10 (Fairchild Republic) aircraft has been obtained during visits and discussions with the following personnel.

Wright Patterson Personnel for A10 10-20-80

Thomas Dickman	Instrumentation
Dave Forman	Flight Reign and Aerodynamics
Robert Tyndale	" " " "

Fairchild Republic 10-23-80

Howard Davies	Manager A10 Eng
Don Brody	Avionics
Hrant Azarian	Instruments
Murray Winkelman	"

The A 10 aircraft is a single seat twin turbo-fan aircraft, primarily designed to provide sustained support in a battle area involving anti tank and anti mechanized vehicles.

It has high manoeuvrability at low airspeeds and is intended for use at low altitudes (50 below 200 ft.) and commonly carries out 4 - g turns at 300 Kts.

The three hundred or so aircraft already delivered have minimal avionics, from aircraft number 431 onwards the A10 will include 1553 A/B data bus and will contain considerably more digital avionics suitable for data recording.

All aircraft contain a stability Augmentation equipment manufactured by G.E. which operates on the elevator and rudder.

Signals from this system we understand only provide delta changes to the inputs from the pilot and give ± 7 degrees of control.

Personnel at WPAFB indicated that future aircraft would be fitted with Infra Red control system from which many of the required signals could be obtained.

Discussions with Fairchild Republic indicate that this IR system was only likely to be introduced if a two-seater version of the A10 was produced and then only would be fitted to this version.

The latter aircraft will contain an inertial Navigation System which will provide some of the required parameters for the purposes of this study on the data bus.

One out of five aircraft has a structural Integrity Monitoring system installed. Details of this system are attached. (Conrac).

A limited number of aircraft will also have a Turbine Health engine monitoring system manufactured by Northrop. It is understood Airesearch quoted for this and have full details of the signal availability. Cpt. Caputto at Kelly AFB is responsible for this programme.

Similar systems are on board the same percentage of F15 and F16 aircraft. For the F15 these are manufactured by Northrop.

WPAFB indicated that a study was being carried out with a view to replacing most of the cockpit instruments with a CRT display.

Both WP and F.Republic stressed a need on any crash recorder to record details of the status of the Master caution indications.

A possible area is available between the engines for fitment of a recording system.

At both meetings it was indicated that the maintenance recording functions should be included within any FDR. This is such that timely maintenance will be carried out on these systems. (At present 60% of flights with this system are operational).

Details of most of the signals should be available within the Interface Control Document (ES - 160 - 80034) and it is thought that Airesearch have a copy.

The main tanks for the aircraft contain up to 10,700 lbs. of fuel, these tanks are foam filled. External tanks if fitted, can carry up to 12,000 lbs. but are not foam filled and are carried below the fuselage.

For this aircraft consideration should be given for recording RPM and engine temperature for the APU as this can be operated in flight, both signals have a range from zero to one volt DC.

Heading	Synchro	*
Pitch	"	*
Calibrated Airspeed	"	*
Altitude Course and fine	"	*
Bank angle	"	*
Roll/Pitch/Yaw Rate (Normal Rate rate is up to 200o per sec.)	not available but will be advised by Fairchild	
Sink rate	Yes derived from altimeter	
Elevator Rudder and Aileron Pos.	No indication	
Angle of attack	Synchro	*
Normal load factor	Analogue DC +10v to -10v	
Rudder Pedal and Stick position	Not available	
Flap position	Analogue 0 - 1v dc	
Speed brake	Fitted to RH side only. Not linked mechanically. type ?	

Landing Gear	two discretes	28v
Mach Number	From Kollsman Instrument	*
Side Slip	Not available. Not possible to fit transducer	
Engine Parameters	To be found from Airesearch	
Oil pressure	Synchro	
Hydraulic	Two systems	
Fuel Quantity	Bingo signal available	
Throttle Position	Two transducers available	
No Afterburner or variable nozzle		
Oil Quantity	Not available	
Generator output	3 power systems should also record bus switching	
Inverter	essential bus only	
A.D.C. Status	available	

Provided on Master Caution panel are indication of Engine Fire and excessive temperature warning together with other signals.

Dave Norman who has been involved in several of the accident investigations was adament that these master caution indications were the only ones necessary to be recorded.

* available on 1553 A/B data bus when fitted.

Crash Surviveable Flight Data Recorder Study

For the MCAIR F ~~18~~ 15 aircraft, discussions were held with Bill Soukup at Wright Patterson AFB on 21st October 1980. The following information was obtained:-

1. Heading ...... 1553 Data Bus.
2. Pitch Attitude....1553 Data Bus.
3. Calibrated Airspeed......1553 Data Bus
4. Altitude..........1553 Data Bus
5. Bank Angle........1553 Data Bus
6. Roll Rate) Available in CADC but may
7. Pitch Rate) require a software
8. Yaw Rate) modification
9. Sink Rate.........1553 Date Bus
10. Elevator Position....Not on F15. Use Stabilator Position -6.5v to +6.5volts DC
11. Aileron Position ± 20o Synchro Null at 0o) 20% of
12. Rudder Position ± 30o " " " ") A/C only
13. Angle of attack 1553 Data Bus
14. Normal load factor 1553 Date Bus
15. Rudder pedal position not available
16. Stick position/force Force sensor fitted equipment would need modification to bring signal out 0 - 10v dc
17. Flap Position 0 - 10volt dc (requires checking)
18. Speed Brake position 1553 Data Bus
19. Landing gear position 1553 Date Bus
20. Mach Number 1553 Data Bus analogue also available
21. Sideslip angle Probably within INS but would require software change
22. Engine RPM N2 only requires checking
23. Engine EGT Not available. Fan turbine inlet temp. available Signal type to be determined
24 Engine Fuel Flow Synchro 0 - 100000 lbs/hr.
25. Oil pressure Synchro adapted MIL-T-25624C
26. Hydraulic pressure 3 systems each has synchro
27. Fuel Quantity 1553 Data Bus
28. Utility hydraulic pressure synchro
29. Throttle position has been fitted on test aircraft but is very expensive. May be more readily available at engine
30. Afterburner nozzle position synchro
31. Oil Quantity not available
32. Generator output 2 systems
33. Inverter output None fitted
34. ADC digital signal available
35. Fire Control system not available

Limit load warnings are provided by discrete signals and are recommended for recording.

A space of 5 x 5 x 16" is available under the left hand air intake which could be utilized for fittment of the system.

It was recommended that the ASIP recorder should be replaced by the CSFDR.

Visit Report to Naval Air Test Centre

PATUXENT RIVER MARYLAND

Department

SYSTEMS ENGINEERING TEST DIRECTORATE

DANIEL M. WATTERS	U.S. Navy	Advanced Technology
NORMAN W. BISHOP	NGL	
V. HUGH EDWARDS	NGL	

Date 25th November, 1980

Dan Watters is in charge of the advanced technology group at NATC. He has been tasked by Ray Rank at NAVAIR to produce statistics of Navy aircraft accidents and an essential parameter list for crash investigation purposes. He gave us all the data that he had collected and promised to give us more when it became available.

Dan Watters is currently drawing up a MIL-STD document for the Navy. This MIL-STD will be the future Navy requirements for crash protected FDRs.

We were then shown the laboratories where work is currently being done to evaluate a semi conductor FDR manufactured by Sperry Univac. The Hamilton Standard system was also under evaluation. Details of these two systems are in appendix one.

It was made absolutely clear to us by Dan Watters that all future crash recorders will be of the deployable type. This is because of the high number of over the water missions that are carried out by the Navy. The cost of recovering an aircraft from the sea bed can be very expensive. With a deployable recorder a decision can be made whether or not to recover the aircraft, thus reducing the costs.

The Navy's position on voice recording is uncertain. Ray Rank tells us that it is only necessary on two seater aircraft, while Dan Watters and the safety office would like to see it implemented on all aircraft. He gave three reasons:-

1. A lot of flying is done out of range of A.T.C.

2. When a pilot is under stress he will normally talk to himself or the aircraft and this data would prove invaluable in establishing the cause of the incident.

3. If a pilot is aware that his voice is being recorded and he experiences any difficulty, if properly instructed, he may talk about the problem.

The only reason that a semi conductor FDR is being suggested is from the reliability aspect. The Navy have had bad experiences with their existing tape recording systems.

N.W. Bishop and myself visited Dan Watters who heads the advanced technology department of the Systems Engineering Test Directorate at the Naval Air Test Centre, Patuxent River. The intention of this meeting was to introduce us to what the Navy are evaluating in terms of Crash Data recording.

Since a F.18 aircraft had crashed at Patuxent River the previous Friday and the MSDR had been recovered, Dan Watters wanted to know a little more about the system.

Data had been recovered sucessfully off the TTM. Unfortunately the last few minutes of data had not been dumped onto the tape and was lost. This is inherent in the design as the system was not designed as a crash recorder but as a maintenance recorder.

He confirmed that the crash hardened MDRM was only an interim solution to the crash recorder design and that a deployable system is necessary. (See visit report to Ray Rank.) He also confirmed what Ray Rank had told us that morning.

Dan Watters has been tasked by Ray Rank to produce crash statistics for the Navy (see enclosed letter). Also he will be carrying out a survey on the latest available semi-conductor memories, as the Sperry Univac system is not considered as the final solution.

We were then given a conducted tour of the Laboratories.

First we were shown the Sperry Univac facility. Here they were using existing Conrac DAU and CPUs controlling a 1553 data bus. The Sperry Univac Solid State Memory is used for storing both audio and data, audio taking up 80% of the storage. This set up is described in more detail in a Naval Document attached. We then moved on to the laboratories where they evaluate recording systems.

A complete aircraft simulator was used to evaluate the recording systems. The simulator comprised of a Dual 1553 data Highway, simulated cockpit with flying controls and controlled by a number of PDP11/34 mini computers. The system could then be programmed to simulate a number of current aircraft in the Navy.

The simulator was flown by an experienced pilot of that particular aircraft and the data generated used to evaluate the AIRS and ULAIDS.

While we were present the Hamilton Standard AIRS was under evaluation. We were shown traces produced by the aircraft, superimposed on this trace was the trace produced after data compression.

By all accounts the set up was impressive and showed how much the Navy are willing to spend on crash recording systems.

A further meeting has been arranged for 25th November 1980.

Meeting at Norton Air Force Base with Lt. Col. Robert Sweginnis and Capt. Dennis Dailey AFISC/SESD 8th December 1980.

Report by N. W. Bishop and V. A. Edwards

The meeting was held to discuss various aspects of the CSFDR study.

Below are the issues raised and relevant comments received.

Engine parameters = we questioned the need for recording each of the parameters N_2, N_1, EGT and Fuel Flow and if any one could be left out.

Each is considered important to enable determination of the cause of failure, N_2 provides thrust information, EGT fuel control data and Fuel Flow, fuel management problems. Sampling rates to be adequate to determine if failure is due to fuel starvation. If EPR is available this would also be very useful.

We were asked what our preference was for solid state memory. We stated that no discussion had been made but indicated that we were considering the Intel E^2. They questioned the write time for these devices.

It was suggested that No~~p~~se wheel steering be monitored in the form of a hard over di~~nn~~screte.

They expressed the opinion that the last 5 minutes prior to crash in an uncompressed state would have advantages but to consider the cost.

Pre take-off data was considered to be useful if not too costly.

Audio was considered to be not cost effective and they would prefer to record additional parameters.

The parameter recording accuracies should be such as to indicate normal instrument fluctuations.

A constant data rate with reduced accuracy during high rates of change was considered acceptable providing the data was compressed during quasi static

It was stated that for the crash conditions one company was taking an aircraft dive into the ground at 600 kts making a 10 foot hole with 15 feet of the aircraft compressed.

ngl memorandum

from N.W.Bishop and V.H.Edwards to

date 24th November

reference Meeting with Ray Rank NAVAIR Systems Cmd. 19th November 1980

A very cordial meeting was held with Ray Rank during which he expressed his views and expectations with respect to future C.S.F.D.R and maintainance recorder programs for the US Navy. He also describe their attainments during the A7 maintainance programe.

CRASH RECORDERS

Ray Rank is adament that for aircraft that predominantly fly over water a deployable recorder is required for crash investigation purposes. This due to the extremly high cost of recovering an aircraf or recorder after a crash. This recorder must contain a Crash Positio Indicator. He indicated his preference for the use of a deployable recorder over land as well, on the grounds that an aircraft which crashes into the mountains or forest is very difficult to find and the C.P.I. would provide a means of locating the crash .

We questioned the airframe modification cost for fittment of an aerofoil which he stated were extremly high.

He is of the view that the C.S.F.D.R. storage module must be separate from any maintainance recorder such as not to reduce its integrity.

For recording of audio, which he does not consider essential on single seater aircraft, his recommendation is that two identicle recording modules should be utilised one for voice and the other for data.

He we understand was one of the two sponsors for the development of the Sperry solid state recorder. He stated that the objective was to have a solid state recorder proven and available to start in service operation in 1986/87.

MAINTAINANCE RECORDING

Ray Rank is obviously one of the prime exponents within the US Navy in favour of maintainance recording. He described the A 7 maintainance program, which was set up to allow comparisons in operating cost and readiness. One half of a squadron opperates a total maintainance policy utilising the Conrec maintenance recording system together with boroscopes and oil analysis, whilst the other half uses normal maintenance procedures. In the early days of the program they had lots of problems but since the bugs have been resolved, the half of the squadron using maintenance recording has consistently more aircraft available to fly.

For the F18 maintenance program he expected at least as much success once the bugs,which he considered inevitable,were overcome.

Visit Report NTSB Washingotn D.C.
Date 8th October 1980
Person visited - Dr. Carol Roberts
Attended by N.W. Bishop and V.H. Edwards.

The meeting was opened by Norman Bishop who explained to Dr. Carol Roberts who and where NGL are in the Aerospace industry.

Dr. Carol Roberts told us that both Hamilton Standard and Lear Siegler had visited NTSB to discuss the programme. Lear Siegler visited NTSB shortly after the contract was awarded and have not been back since, while Hamilton Standard have visited NTSB on a couple of occasions.

Dr. Carol Roberts summerised NTSB philosophy on accident investigation as well as changes whe would like to see come about. In general these thoughts agreed with Ray Davis's, the exceptions where Data Compression, Compatebility of TSO-C51A to military aircraft and CVRs in single seat aircraft.

Data Compression would be acceptable as long as the last 5 minutes were uncompressed and continuously recorded.

The TSO-C51A spec. needs modification in two areas (1) to withstand greater impact velocity (2) shorter but much hotter fire survivability.

CVR's according to Dr. Carol Roberts in a single seat fighter aircraft would not serve an important role in accident investigation but it is essential that time correlation between data on the FDR and the ATC tapes is maintained.

We were then given a conducted tour of the data replay facilities and introduced to Paul Turner.

Paul Turner is in charge of the CVR replay facility and was surprised to find out that we manufactured a CVR. He said that he was willing to help is any way with tape handling problems if a similar situation like that of the F18 happened in the U.S.

Dr. Carol Roberts then gave us various papers and documents relating to commercial aircraft.

Crash Survivable Flight Data Recorder (CSFDR) study

Report of actions and progress 16th October to 1st November by E.W.Bishop and Hugh Edwards.

We visited Wright Patterson AFB 20th and 21st October. Information relating to the F16 was obtained from Melvin Leraas ,Paul Anders and Lt. Stephen Haupt, details of this are in a separate report passed to Nick Bullock. A meeting was held with Thomas Dickman to obtain informatio with regard to the A10. Aseparate report passed to Nick Bullock covers the information obtained during this meeting and a meeting heldwith engineers at Fairchild Republickon 23rd October. We also met with the persqnnel responsible for the structural integrity program for all three aircraft being considered andwith Bill Soukup who is responsible for the F15 instrumentation.

Robert Gemin the engineer responsible for the CSFDR program accompanied us during all the meetings except that with Paul Anders and Lt. Stephen Haupt when Maj. Schopf was with us.

On 29th October we visited MCAIR at St. Louis to try and finalize the details of the signal sources on the F15 and to determine if a suitable location for fittment of a system were available. The meeting was set up and arranged by Frank Wynn the local Garrett area representati who attended with us. The engineers headed by Michael Inman stated that they were only prepared to talk with us in general terms, if we wished to obtainaany specific information we would have to place a contract to obtain that information.

We understood that Hamilton Standard had placed suchaa contract with them and that they felt moraly commited to treet other companies the same way. All of the engineers present expressed adesire to have a crash recording system fitted to the aircraft.

We have spoken with NASA Langly and a Dr R.G.Thomson of the Impact dynamics research facility provided us with the results of calculations for the maximum shock expected to be seen by equipment mounted in a fighter or attack aircraft that crashes. He also provided us with the name of an engineer at Moffat field California who has carried out work to determine the temperatures and duration of a fire resulting from crash of these type aircraft. Ray Conlisk with whom we keep close lieson is to contact him.

John Finger at NASA Langly research centre is carrying out a study into methods of obtaining statistical data for aircraft structural streng requirements. He has promised to forward us details of this work and of the aims of the study. I have sent him a copy of our proposal for the CSFDR study. After he has read this he would like to meet with us if he feels either he could help with our study or that we could help in his .

We have spoken with AVRADCOM at Ft. Eustace who contracted Hamilton Standards for the production of the AIRS system,but obtained little information not already known. We did however learn that a Mr. Tom House at Ft. Eustace was investigating the feasability of fitting a maintainanc recording system on the Black Hawk helecopter. When he returns next week we intend to contact him.

We have been in touch with personnel at Marshall Space Centre in an attempt to obtain details of data compression systems and are following up contacts provided by them.

ngl memorandum

from N J O Bullock ext. 234 to Mr V Otto
Mr D Hooper

date 15th September 1980

reference NJOB/BRB/493

cc Mr R Strange
Mr J Brooking
Mr H Edwards
Mr N Bishop
M/F File

Subject: <u>Notes on visit to AIB to discuss Wright-Patterson Study</u>

A visit was made by H Edwards and N Bullock to the Accident Investigation Branch, Farnborough on 11th September.

The purpose of the visit was to discuss various aspects of the crash survivable recorder study being carried for the Wright-Patterson airforce base.

The person contacted was Mr Ray Davis, Senior Inspector of Accidents.

We outlined the overall task and explained that at this stage we are primarily concerned to gather opinions as to the necessary parameters to record together with sampling rates etc. We asked Mr Davis to advise on other sources of this data and he provided the following information:-

<u>RAF</u>

In the event of an accident a board enquiry is set up. It consists of the President who is an officer (from another station) of higher rank than anyone involved, a pilot who is'current' on the aircraft type and an engineer officer. The AIB are called in to give engineering advice and in cases where there is a FDR advise on replay.

<u>Army</u>

The Army has its own accident investigation branch at Middle Wallop and the person in charge is Major Burt Reed.

<u>Navy</u>

The Navy also has an accident investigation branch which is at Lee-on-Solent.

Both the Army and Navy AIBs are mainly concerned with helicopter accident investigation. None of the Army or Navy aircraft or helicopters carry crash recorders.

Other useful information obtained regarding the RAF is that at present the only aircraft fitted with crash protected recorders are the Tornado, the Hawk and the VC10, although it is anticipated that the Jaguar will be retrofitted. The RAF have a flight safety branch known as IFS and the person in charge is Wing Commander Ray Hancock whose telephone number is 01 430 7025. His boss is an Air Marshall whose name Ray Davis has promised to give to me.

Cont'd.

Wing Commander Hancock has been writing up a requirement for recorders to be fitted on RAF aircraft, however the responsibility for such a decision rests with the Air Eng department and contact there is Squadron Leader Peter Sharp. His address is Air Eng 12a, Old War Office Building, Whitehall, Telephone 01 218 5115.

There has been resistance in the RAF to the fitting of crash recorders on the basis of lack of space and cost. Many times the Accident Investigation Branch have convinced IFS personnel of the necessity for recorders but then these personnel have been posted to other jobs before any implementation of the recommendations. Other sources of information suggested were BAe Warton, NAMA, The Flight Test Instrumentation Department Telephone Preston 633333 extension 336, Mr McFarland, Mr Maychin. They have much more experience on high performance aircraft.

BoscombeDown have the replay facility for the Hawk and will probably get one for Tornado.

British Aerospace Kingston might have experience with regard to the Hawk. There is a replay at Dunsfold.

BAe Brough have flight test instrumentation experience on the Phantom and Buccaneer. Their facility for recording is at Holme-on-Spalding Moor.

Mr Davis did not seem to think that a great deal of information could be obtained from other sources in Europe they tend to follow the British and American lead. The French have a crash recorder replay facility at their equivalent of our CAA which is at Bretigny. Germans are created a facility at Brunswick. A useful source of information is likely to be a Bernard Craiger of the National Research Council in Ottawa. Particularly ejectable recorders.

AIB Status and Structure

The Accident Investigation Branch is a branch of the department of trade which means that it is separate in its control from the CAA. CAA is the regulatory body and the AIB advises them and they then cause the regulation to be inacted. CAA liaises in an Accident Investigation but has no power in the investigation itself. The AIB is headedby a Chief Inspector and a Deputy Chief Inspector and beneath them are four branches three of them being operational branches and one engineering. Within the engineering branch there are two Senior Inspectors of accidents, one being Ray Davis and the other Peter Shepherd. They have the responsibility for replay of civil Cockpit Voice Recorders and Data Accident Recorders. The total staff of AIB is something in the order of 35 and is tending to increase slightly and approximately half the workload is RAF crashes.

Survivability requirements

Mr Davis considers that the present survivability requirements as defined in CAA Spec 10 are adequate in that equipment that is produced to meet them generally survives, although in some cases the severity of the accident may exceed the specification. Mr Davis said that in all but three recent accidents the recorder had survived quite adequately. The three he quoted where the crash exceeded the specification are: the Viscount that crashed on an autobahn the 707 that crashed in Rome where there was an extremely hot fire, and Vanguard EE that crashed at Heathrow and again it has been estimated that the fire well exceeded the specification. In all three cases most of the data was retrieve from the recorders in spite of the severity of the accident, although in the case of Viscount only limited data was recovered.

As a part of the survivability discussion we asked Mr Davis his views on ejectable recorders. He said that in the vast majority of cases the recorder is found amongst the wreckage and that if it were ejected it might be lost. The last recorder that was lost was when the Comet went into the Mediterranean. For civil application ejectable recorders are not acceptable because of the danger of them being spuriouslyejected and either resulting in loss or possibly injuries to passengers. The other point against them being extra and more difficult maintenance.

Mr Davis told us that Easams had done quite a lot of work on survivability requirements.

He stated that in his opinion seviceability is far more of a problem than survivability. Built in test and maintenance requirements need tightening up much more. His opinion is that military survival requirements do not need to be different from civil. However he made the point that the operating environment is far more severe in terms of g-loads during manoeuvring He stated that the preferred mounting position is aft of the rear pressure bulk head. This is an area on both conventional and rear engined aircraft that is often substantially less damaged than the rest of the aircraft.

Error Rate

In connection with his statement that serviceability is more in need of tightening up than survivability I asked him his views on error rate. He feels that the error rate in specification No. 10 is probably just satisfactory but that most equipment usually does much better than the one word in 10^4 specified and ocassionally they still have trouble. A more realistic figure that is possible to meet would appear to be one in 10^5.

Duration and compression

As an immediate response to the question of duration Mr Davis made the following comments.

1. That it should not be less than the aircraft sortie capability.
2. That one or two previous flights were extremely useful to sort out spurious information such as incorrect transducer calibration.
3. That two to four hours would be a bear minimum for a single seat aircraft.
4. That if milking can be done without degrading the recording a single flight duration would be satisfactory. However if milking is opted for facilities have to exist in all stations where the aircraft may commence the flight.

Mr Davis is opposed to compression because nobody has convinced him that there is a system which can be used that will not lose essential data. Possible means of compression is changing the parameters that are being recorded depending upon the flight condition. Compression of the audio signal would be completely unacceptable because they use the signal for detecting the operation switches and analysing all sorts of sound that would probably be below the threshold of operation. They also listen to crew breathing.

Thirty minutes duration is probably satisfactory for military aircraft.

Parameters

Prior to the meeting we had produced sheets with possible parameters listed and spaces provided for sampling, accuracy etc. Mr Davis promised to have a first attempt at filling in these sheets in the next two weeks. There was a wide discussion on the question of parameters and the following points emerged:

Mr Davis considers that audio-both voice and general cockpit sound is essential. Less useful on a single seater aircraft because of less speech but still very useful. Relative time between events on the aircraft is very important and relative time between aircraft and ground events is equally important. Elapsed time and the means correlation between aircraft time and ground time such as press to transmit is more useful than GMT because, surprisingly, ATC times at different towers can very by upto 2 minutes.

Other points from the parameter list are (a) Normal acceleration is the same as normal load factor (b) Roll attitude is the same as bank angle (c) Primary flying controls are the same as aleron/elevator/radar position.

DME (Distance Measuring Equipment) would be a useful parameter to record on military aircraft.

Mr Davis mentioned in conversion that British Airways have a solid state recorder which they use on Concorde which retains information for a few hours after landing. Peter Waller is responsible for it and is also generally liable to be a useful contact. He thinks that Plessey are probably the manufacturers. The recorder is used to record details of exceedances such as over temperatures on engines and he thinks it can be programmed in flight by the crew to record details of any exceedances noticed.

NJOBullock

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N J O BULLOCK
Project Engineer

ngl memorandum

from	N Bullock	ext. 234	to Mr V Otto Mr D Hooper
date	23rd September 1980		cc Mr R Strange Mr J Brooking Mr H Edwards Mr N Bishop M/F File
reference	NJOB/BRB/496		

Subject: Notes on visit to British Airways, Engineering to discuss Wright-Patterson Study

A visit was made by H Edwards and N Bullock to the British Airways Engineering Base, Building TBK at Hatton Cross,(PO Box 10, British Airways, Heathrow Airport, Hounslow, Middx, TW6 2JA) on the 23rd September 1980.

The purpose of the visit was to discuss various aspects of the Crash Survivable Recorder Study being carried out for the Wright-Patterson Airforce Base. The person contacted was Mr Peter Waller, Senior Principal Engineer Flight Data Recording.

As the meeting had only been arranged the day before it had not been possible to send the letter (NJOB/BRB/495) confirming the appointment and outlining the topics to be discussed. I therefore gave Mr Waller a copy of the letter.

Mr Waller promised to give consideration to the questions when he had more time. I said I would send him a copy of our questionnaire as soon as it is complete and he said he would fill in those parts of it that he could providing it did not require too much time.

The meeting then consisted of a general conversation about various aspects of aircraft recording and of the task of the study. Mr Waller believes that the maintenance recording aspects of aircraft recorders are extremely important, and that even if they are not intended for this purpose almost certainly the operators will want to use them either for maintenance purposes or for investigating malfunction reports. He quoted as an example that the Hawk crash recorder had been used to investigate incidents that would have probably lead to a grounding of the aircraft if the information had not been available. He also said that Bernard Craiger's paper to the ISASI Annual Seminar at Montreal in September 1979 contains useful information on this subject. A very important consideration if recorders are to be used for maintenance purposes is access to the data. This can either be done by 'milking' the recorder or by removing a cassette. Mr Waller quoted the Lockheed recorder and the new Sunstrand recorder as examples of those that can be 'milked'. The Lockheed can be replayed at approximately 30 times the tape speed and 4 tracks at a time. The new Sunstrand recorder is at Data Acquisition and recorder in a ½ATR case and can bemilked in approximately 15 minutes. Mr Waller expressed the view that 15 minutes was the maximum acceptable 'milking' time. He doesn't regard 'milking' as a method which is acceptable to British Airways because it involves having a large number of personnel and a lot of equipment.

I asked whether he knew whether the Plessey Lockheed 'all in one' system has sold in any quantity, he said it had not they believe because legislation had not yet demanded that it should be fitted.

British Airways are seeking tenders for supply of a maintenance recorder for use on their Boeing 757 aircraft. It will use a 3M band drive type cassette which has been developed to a state where it is capable of recording approximately 15 mega bits. British Airways have only sought quotes from companies that they feel have equipment which is at least near to their requirement. The companies in question are Hanbush, Penny & Giles, Davell and Peripherals Development Associates of Costa Mesa, California. It appears that they are connected with Douglas Longbeech because we saw a paper which was jointly prepared by them and one Anthony Aquion of Douglas Aircraft Company.

The crash recorder on the 757 will either be the new Sunstrand system or the Lockheed, Penny & Giles or Davell. The Sunstrand is standard fit but BA are slightly concerned as to whether it will in fact be available in time. Eastern Airlines are opting for Lockheed. I got the impression British Airways do not favour the Lockheed. All four recorders are capable of recording 64 12 bit words per second.

Mr Waller outlined the background to BA's maintenance recorder activity. They started many years ago experimentaly monitoring one engine on the Vanguard to see whether such a system were possible. The next step was to measure maintenance parameters on all three engines of the Trident 1 and then a more sophisticated system on the Trident three which was considered to be just cost affective providing the equipment could be installed in a new aircraft however retro fitting would not be justified. Maintenance recording is now advanced such that on Tristar maintenance is entirely determined by the recorded data. At present the recorder is removed from each aircraft every day and the analysis is not available until a day and a half later. However on the new system it is intended to make a quick appraisal of the data much more quickly than this and a full analysis later. The present cassettes have capacity of 14 hours flying and generally an aircraft will only do about 8 hours flying a day.

KLM have done some work on a form of data compression but it was not very successful. The person to speak to at KLM is Henk Vermeulen, Telephone 01031 20491479.

BA have looked at solid state recorders particularly bubble memories but do not believe that the difficulties with high and low temperatures have been solved, they also consider that the stability of the chips is not adequate for the shocks that would be experienced in a crash.

For maintenance purpose it is only engine parameters that are recorded, however from the point of view of assessing aircraft state of health normal 'g' is used and compared with the manufacturers fatigue calculations for the purpose of extending fatigue life of the wings. As a rough rule of thumb the data capacity required for maintenance data is comparable with that required for the mandatory parameters.

Mr Waller expressed the opinion that the USA is primitive in its use of maintenance data by comparison with Europe certainly in civil operations.

Other people who might be of help to us are: Swiss Air, Robert Lüscher in Zurich, Telephone 01 812 7669, and at DLH, Peter Ladwig, he is Hamburg Telephone 040 509 2304.

The AIDS Replay facility at British has been developed mainly for the Tristar fleet.

The system is based on a LS1-11 minicomputer. The data is read off the tape and processed using a bit-slice microprocessor. The processing corrects timing errors and decodes the data to NRZ. The sync is then removed and the data assembled into word blocks by a further processor.

The data is then processed by the LS1-11 which separates the decrete signals out of the 12 bit words and presents the data in engineering units in graphical and or in a tabulated form.

N J O Bullock

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N J O BULLOCK
Project Engineer

Footnote

1. The Sundrand 'Universal Flight Data Recorder' data sheet states that the replay time is 30 min not 15 min as in the above notes.

2. The Fairchild 'Digital Flight Data Recorder' F880 data sheet states that the Quick Access Cartridge (which appears to be a 3M type) has a capacity of 69 Mbit. However I got the impression from Mr Waller that the F880 might not actually exist yet.

ngl memorandum

from	N J O Bullock	ext. 234	to Mr V Otto - Garrett, Torrance Mr D Hooper
date	9th October 1980		cc Mr R Strange Mr J Brooking Mr H Edwards - Garrett, Torrance Mr N Bishop - Garrett, Torrance M/F File
reference	NJOB/BRB/503		

Subject: Notes on visit to RAE Structures Department to discuss Wright-Patterson Study

A visit was made by N Bullock to the Royal Aircraft Establishment Structures Department, Farnborough, Hants, GU14 6TD on the 3rd October.

The purpose of the visit was to discuss various aspects of the crash survivable recorder study being carried out for the Wright-Patterson Airforce Base. The person contacted was Mr John Sturgeon of the Structures Department. Mr Sturgeon has been involved with certain aspects of accident investigation for many years and is frequently consulted on recorder and recording requirements by the RAF, CAA and others. He was closely involved with the Tornado recorder specification and with the selection of the contractor.

The first part of the meeting took the form of a general discussion and the following points emerged:-

A negligible number of accidents are caused by aircraft structural failure or engine failure. Before there were accident recorders virtually all accidents were concluded to have been caused by pilot error but it was not discovered why the pilot had made an error so that prevention of a reputation was unlikely. With the advent of recorders it has been possible to discover why the error was made and take corrective action. An example of this was the Trident crash at Madrid which was caused by the aircraft attitude affecting the airspeed sensor in such a way that as the aircraft rotated after take-off there was a 5 - 10 knots reduction in indicated airspeed which led the pilot to believe that he had had a double engine failure.

It can be seen from the above example that there is a good case for the recorder recording the signal which is displayed to the pilot, however it is vital that it is not degraded in the process of recording it.

There is also a case for recording the same parameter from an independant source and indeed recording both signals.

Mr Sturgeon said that most accidents occur during landing, approach or hold and are because several things occur simultaneously. The human brain can cope with two variables going outside normal limits at the same time but if a third area needs attention it is either left unattended or one of the first two is forgotten.

Mr Sturgeon said that the actual rate of roll and pitch on modern military aircraft is less than it used to be, a typical time to go from straight and level to 90° bank is 1½ seconds and to go from straight and level to upsidedown 2½ to 3 seconds.

Duration

Mr Sturgeon's opinion is that in a vast majority of cases it is the last few seconds of data which is most significant. There is little advantage in going beyond the accident flight and the previous landing, however the whole of the previous flight can be useful. The previous landing and the take-off and climb give confidence that the sensors are properly calibrated. To satisfy the above about 2 hours are required for fighter trainer aircraft and 10 hours for transport bomber aircraft.

Inclusion of Voice

Mr Sturgeon does not regard voice as being nearly as important as Ray Davis but believes that it is not a large penalty and should be included in future recorders. A duration of 15 minutes would be sufficient as a minimum compared with an absolute minimum of 30 minutes of data.

Serviceability and Emergency Operation

Mr Sturgeon felt quite strongly that the biggest change needed to present recorders was a large increase in reliability. He said that the chances of a recording system working perfectly at the time of an accident was probably less than 50%, maybe as low as 10% because built-in test on most recorders does not adequately test the system, certainly does not test the transducers.

He believes that the only way to be certain that an accident recording system is functioning correctly is to replay a complete flight and he said that it should be possible to do this without removing the recorder from the aircraft. He also said that if the MTBF of the system is 1000 hours (which, in reality is all that is likely) there needs to be a replay every 50 to 100 hours in order to give a reasonable confidence level.

Mr Sturgeon does not think it is possible to make a recorder that would work after impact or that this would be particularly useful. On the Tornado the recorder stops when the a.c power fails. If the recorder is run from the emergency d.c supply you either have the increased weight penalty of a larger battery or reduction in the emergency power available for flying the aircraft. One has to chose whether to use all emergency power to try and save the aircraft and pilot or whether to use some of it to keep the recorder running and therefore know why the aircraft has been lost.

Compression

Mr Sturgeon does not believe that data compression is possible without loss of valuable information. He quoted the Buccanneer that crashed in Nevada where everything was normal up until 3 seconds before break-up and therefore it was the last 3 seconds of data which allowed analysis of the accident and this would probably have been lost or degraded had a compression system been in use. He also said that the memory that would be necessary with a compression system would have to be crash protected which would either need a separate crash protected package or an increase in cabling between the acquisition unit and the recorders.

Ejectable recorders

He is against ejectable recorders. He said that if recorders are mounted in the tail there is a 95% chance of finding them and of then having survived the accident adequately. The chance of finding an ejectable recorder is much less, he said that in many cases the radio beacons do not work if they land say in a wet forest and , even if they work it is impossible to get them out of a very rough sea.

Survival

Mr Sturgeon expressed the view that there was a 95% survival rate of recorders designed and tested to CAA Spec 10 requirements. This was slightly contradictory because he had previously said that the survival requirement should be to the original Tornado levels which were subsequently substantially reduced.

Maintenance

He did not seem to think that a great deal could be gained from maintenance recording but thought that if the recorders were in daily use on a task in which the operator was interested at least it meant that they would be kept working. Although not a maintenance recorder the Hawk unit can be milked in about 20 minutes. He said that the Tornado recorder would be converted to fast replay sometime in the future, he does not believe that it would be possible to replace it with a solid state memory.

Parameters

The signals that are recorded should be those that are displayed to the pilot. The most important are the following:

The three linear accelerations, pitch, roll, heading, position of major control surfaces, status of auto stabilisation system and auto pilot, some engine information to give some idea of thrust for example engine pressure ratio (possibly throttle position as an alternative). The minimum sampling rate should be 8 times per second and Mr Sturgeon thought that it was better to have a high sampling rate on a few parameters rather than more parameters at a low sampling rate.

I left a copy of the Questionnaire with Mr Sturgeon and he promised to fill in those parts of it to which he could make a useful contribution when he had time.

I took the opportunity of showing Mr Sturgeon the F18 TTM and he was very impressed by the design and felt that it was one of the few recorders that he had seen that was likely to work under the angular acceleration conditions that exist in aircraft although not in the environmental specifications.

N J O Bullock
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N J O BULLOCK
Project Engineer

ngl memorandum

from	N J O Bullock	ext. 234	to Mr V Otto - Garrett, Torrance Mr D Hooper
date	23rd October 1980		cc Mr R Strange Mr J Brooking Mr H Edwards - Garrett, Torranc Mr N Bishop - Garrett, Torrance M/F File
reference	NJOB/BRB/509		

Subject: Notes on visit to Easams Ltd to discuss Wright-Patterson Study

A visit was made by N Bullock to Messrs Easams Ltd, Lyon Way, Frimley Road, Camberley, Surrey, GU16 5EX on the 20th October. The purpose of the visit was to discuss various aspects of the crash survivable recorder study being carried out for the Wright-Patterson Airforce Base. The person contacted was Mr Dave Gill, Senior Engineer, Recorders. Mr Gill has been with Easams for three years and is their recorder specialist. He has been concerned with Tornado,Hawk and Nimrod recorders amongst others. Prior to working at Easams he had spent seven years at the RAF Central Servicing Development Establishment at Swanton-Morley in Norfolk. One of their chief functions is to advise the Ministry of Defence on questions concerning maintainability. They also have a maintainability data bank and industry to get information on MTBF of various equipments. A general discussion was held and the following points emerged:

Mr Gill did not have any specific information on survivability requirements but thought that the present spec 10 levels were adequate and reiterated the views of others that serviceability and built in test is the area that needs improvement far more than survivability. He said that as a rule of thumb the MTBF figure achieved on military combat aircraft was only one sixth of that achieved with the same equipment in civil aircraft. In his experience electronic equipment with a built in test calculated confidence level in the 90% would in fact only achieve something in the order of 70%, and on recorders produced to date the built in test probably only detects something like 25% of all failures. In practice a system MTBF of about 200 hours is all that is achieved. However this does not present as big a problem as it might appear because the average flying time for combat aircraft is only 300 hours per year. Nimrods flying time would of course be much more.

In his opinion the only way of proving that a system is working correctly is to replay the information. This can either be by use of a quick access duplicate record or by milking the recorder. He does not feel that the quick access approach gives sufficient confidence that the main recorder is working since this is the most unreliable part of the system. The milking rate normally required is 8 - 10 times record speed, however for the purpose of verifying that the system is working it is sufficient to replay say the last 15 minutes of a flight. This would show decent from a known altitude at a known glide slope and landing at a known airfield and would give a reasonable degree of confidence in the transducers. The required periodicity of these check replays would be about 75 hours.

The required duration should be that required for one complete flight which on the combat aircraft is probably 2 - 2½ hours, on trainer aircraft 1 hour and on transport bomber aircraft 8 - 11 hours.

Mr Gill was dubious about the usefulness of voice because of the limited amount of communication on the aircraft;most being with the ground which is recorded anyway. He felt that general cockpit audio was probably not useful because of the very high noise level and that if you did have it for the point of view of recording switch operations and so forth it would have to be on a separate channel from speech. Voice duration on the Tornado is 40 minutes and data 120 minutes.

On the general question of parameters and sampling rates he said that on Tornado the parameters had been decided by John Sturgeon and he had no reason to think they are wrong but the sampling rate on such things as the status of terrain following equipment probably needed to be much faster say 32 samples per second.

The recorder should be located at the rear of the aircraft for best survival chances. On ejectable recorders he said one argument in favour,that the Canadians advance is that in their conditions of extremely low temperature and high probability of snow fall they can recover them quickly. However Mr Gill expressed the view that there could equally well be circumstances in which it was not possible to search for them at all because of bad weather conditions within the life of the radio beacon, in such circumstances it would be better for a recorder to be with a large mass of wreckage which could be found later. He did not think anybody had done a real analysis of the pros and cons of ejectable recorders. He thought there was a good deal of prejudice on both sides. One argument against them which he sympathised with was that because the forces acting during a crash situation are outside normal limits it is quite possible for them to deploy prior to the accident and therefore not record the conditions during the last vital moments before impact.

He did not have any views on cost but did mention in conversation that the Tornado cassette voice recorder, which is also used for computer loading,costs about £3000 and is now working well. They are successfully using it to load the computer at -30°C.

As another comment on sampling rate he mentioned that the lateral acceleration on the Hawk could change extremely quickly and is very critical and should probably have a sampling rate of 32 samples per second.

I left Mr Gill a copy of our questionnaire and he promised to fill in those parts where he could make a useful contribution as soon as possible.

Mr Gill asked whether it would be possible to have a copy of our report and also whether it would possible for the fact that Easams have made a contribution to the study to be mentioned in the report. I said I would endeavour to make this possible.

Mr Gill suggested two people that it would be useful for us to speak to. Herr W Bauer at MBB Ottobrunn, and Gordon Hurry MOD RD Eng 4 at Prospect House, Tel 01-632-6321.

I took the opportunity of showing Mr Gill the F18 TTM and gave him a data sheet and descriptive leaflet.

N J O Bullock

N J O BULLOCK
Project Engineer

ngl memorandum

from	N J O Bullock	ext.	234	to	Mr V Otto - Garrett Torranc Mr D Hooper
date	18th November 1980			cc	Mr R Strange Mr J Brooking Mr H Edwards - Garrett Torr Mr N Bishop - Garrett Torra M/F File
reference	NJOB/BRB/518				

Subject: Notes on visit to Civil Aviation Authority to discuss Wright-Patterson Study

A visit was made by N Bullock to the Civil Aviation Authority, Brabazon House, Redhill, Surrey RH1 1SQ on the 12th November. The purpose of the visit was to discuss various aspects of the crash survivable recorder study being carried out for the US Airforce Systems Command Wright-Patterson Airforce Base. The persons contacted were Mr T O'Brien and Mr N Ferrett.

Duration

The view was that the minimum duration should be one complete flight, there was some sympathy for the idea of recording the take-off and the last few minutes of flight but in some cases a complete recording is necessary where for instance a navigational error has been made. In any case it should be at least the last 30 minutes that is recorded rather than the last 15 which has been suggested. On the question of data compression it was felt that this was not feasible in a tape system because this would mean incremental tape motion with consequent increased complexity and unreliability and also mean some tape wastage. It was however felt that with the solid state memory system it could give advantages of being able to record additional parameters. In any event there must be no loss of recording accuracy.

Survivability

The present specification ten survivability levels are regarded as adequate providing the recorder is mounted in the rear of the aircraft and probably secured. It should be as far aft as possible and remote from sources of fire. It must remain attached to the local structure of the aircraft and this can be a problem particularly if anti-vibration mounts are employed. It was agreed that the actual test method involved in the survivability tests needs specifying particularly the base on which the unit is mounted during penetration tests and also in the case of the fire test the fact that the most vulnerable part of the recorder should be subjected to the fire. The survivability test levels were examined in some detail about 8 years ago by the working group which preceeded the issue of spec 10 they were based upon the requirements in TSO C51a which was evolved about 10 years ago. Mr O'Brien said that no recorders designed to spec 10 requirements had failed to survive in accidents to date. Mention was made of the fact that the voice recorder survivability requirements are of a much lower level than the data recorder ones, Mr O'Brien said that this was for historical reasons and that at the time the specification 11 requirements were written there were no voice recorders that met the more severe requirements and therefore it would have been pointless to call for them, however he agreed that both recorders should be subjected to the same survivability tests.An ICAO Working Group is looking at new requirements for both data and voice recorders and this will almost certainly recommend the same levels of crash survivability for both. The Chairman of the ICAO Working Group is Bill Trench of the British AIB. (He is likely to be attending the next meeting of WG21).

Serviceability

It was agreed that there is a vital need to have a high level of serviceability. Mr O'Brien said that Spec 10 required 90% confidence that the system is functioning. He said that in fact this was much too low a number and it should be something like 99% but on the other hand it was quite hard to achieve. I mentioned to him that some people I have spoken to have suggested that the average availability is only something like 50%, he said that he thought it had improved a lot on more recent recorders and they probably do achieve something like 90%. Periodic replays are required at intervals which vary from 6 months to much longer, I think that the variation is at the discretion of the local CAA surveyor. It was agreed that if the recorder could have a maintenance function this would be very useful as the operators would then make sure they remain serviceable.There is a requirement on Civil Aircraft that the recording of one complete flight (I am not sure what the duration has to be) is held for comparison purposes in case accident, this could present a minimum duration requirement.

Cost Benefit

CAA are not aware of any study to show that the carriage of recorders is cost beneficial in terms of saving aircraft. However they are certain that it is essential to determine the cause of accidents and that recorders are an extremely valuable aid in the process and are likely to become more necessary as aircraft become more complex and larger and therefore more likely to be totally destroyed by fire.

Deployable Recorders

CAA are not in favour of deployable recorders for the following reasons:

Because they are not crash protected they may be damaged after deployment, they may be lost because of failure of their location beacons, they are more complex to maintain, they may be deployed in error and even cause an accident themselves, they have to be located in an area of the aircraft where the environment is worse and extra cabling runs are involved.

Questionnaire

I left a copy of our Questionnaire and Mr O'Brien promised to complete those parts of it that he could. He commented on the parameter list to the effect that it would become necessary to record the information being presented to the pilot by the cathode ray displays which will shortly become current. He agreed that the formulation and implementation of any new requirements was bound to lag the actual use of these displays.

NJO Bullock
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N J O BULLOCK
Project Engineer

ngl memorandum

from	N J O Bullock	ext. 234	to Mr V Otto - Garrett Torrance Mr D Hooper
date	1st December 1980		cc Mr R Strange Mr J Brooking Mr H Edwards - Garrett Torrance Mr N Bishop - Garrett Torrance M/F File
reference	NJOB/BRB/522		

Subject: Notes on visit to MOD to discuss Wright-Patterson Study

A visit was made by N Bullock to the MOD Inspectorate of Flight Safety at Adastral House, Theobalds Road, WC1X 8RU on the 25th November. The purpose of the visit was to discuss various aspects of the crash survivable recorder study being carried out for the US Airforce Systems Command Wright-Patterson Airforce Base.

Background

—————— sketched the background on flight recorders to the present time. He said that because of the cancellation of TSR2 and the P1154 the RAF had lost a generation of flight recorders. They had had bad experience with wire recorders and because of this there is a lot of prejudice against recorders in general. Currently the only two fighter trainer type aircraft which have recorders are the Hawk which has a Leigh M10 data only recorder and the Tornado which has a Sperry SCR200. This has four 40 minute tracks giving 40 minutes of voice and 120 minutes of data at 128 words per second,10 plus 2 bit words. He said the present system only uses approximately 70 of these words, but I know from speaking to other people that there are a lot of different demands upon the spare capacity. The Jaguar aircraft being supplied to the Indian Airforce have a Sperry SCR300 which has six 30 minute tracks and is quite flexible in operation. It appears that the tracks can be allocated in such a way to change the ratio of voice to data time and according to —————— there is a large measure of flexibility in the acquisition unit to cope with different signal types and sampling rates. He feels that this is an essential feature to build into any new design.
Both the Hawk and Tornado recorders are being modified so that it will be possible to milk them.The milking facility isbeing added so that the recorder serviceability can be checked but also to provide easy means of extracting data to investigate an incident.An example of this was a complaint from a pilot that an engine failed to re-light and an expensive investigation procedure which would have included sending the engine back to Rolls Royce was avoided because the data on the recorder showed that he had attempted a re-light in less than the stated time. —————— chief aim at present is to get the RAF Jaguars retrofitted with the SCR300, he says there is a lot of resistance because of lack of space on the aircraft, because of the cost of the equipment (it appears that they only look at the cost of the equipment this year not the savings to be gained by not losing aircraft and pilots over succeeding years), because of the weight penalty (from the operations point of view) because there is reluctance amongst pilots(who are very influential in the airforce)to "gadgets" and particularly to a gadget that could be used as a "spy in the cab".

Cost Saving

—————— said that there was a huge potential for saving money by saving accidents. A fully trained pilot is currently worth 1¼ and 1½ million pounds, a navigator about a million pounds, aircraft cost upto eight million

Cont'd.

pounds added to which there is the cost of salvage and accident investigation and of grounding a fleet while investigation is carried out. Approximately 18 Jaguar aircraft have been lost, in 9 cases the cause is unknown or proven. It is thought that in most cases it was failure of the navigation equipment and Sqd. Ldr. Stickley feels that probably 25% of these losses could have been saved had an accident recorder been fitted. The cost of retrofitting all Jaguars would be saved by the saving of one aircraft.

Voice

______________ view is that voice should be included, he said that it had been extremely useful on the two Tornado accident investigations. Only the last five minutes is critical but it is very useful to be able to look back further and see whether the crew had been under stress or had been behaving normally prior to the accident situation arising.

Future Aircraft

______________ view is that future aircraft recorders will be even more necessary than they are now because where an electrical control system fails there will be no evidence in the wreckage such as broken control rods as there is in the mechanical system and cathod ray cockpit displays mean that you cannot determine what the aircraft was doing from jammed instrumentation.

Replay

______________ feels that recorder designers pay much too little attention to replay equipment. He said that Slumberger have an extremely sophisticated 3 dimensional display system with which it is possible to reinact the behaviour of the aircraft from the information recorded. Contact on this subject would be Lou Levey at BoscombeDown.

Survivability

______________ did not have any firm information on survivability requirements, he thought that Sqd. Ldr. Peter Sharp would be best source of this information. He did not know but thought thet Farnborough had probably provided the information to go into Procurement Specification in this respect. His feeling is that the survivability requirements for low level high speed military aircraft should be more severe and those civil aircraft.

Ejectable versus Contained

______________ is fairly open minded on this subject but has a preference for ejectable recorders this in contrast to everybody else I have spoken to. I got the impression that his opinion might be more subjective than scientific, he showed me a number of photographs of crashes where there were no recognisable parts left of the aircraft and seemed to imply that a contained recorder could not have survived. He also said that when an aircraft goes very fast into water it breaks up to such an extent that there are no large parts left to which the recorder could be attached and the recorder being heavy tends to sink into the mud. In contrast an ejectable recorder can be picked quickly and will avoid damage. However, Sqd. Ldr. Sharp of Air Eng is against ejectable recorders because of the extra complexity of the various water heat and shock sensors that are necessary to release them. This complexity can either lead to spurious ejection or to failure to eject in an accident. One of the German Tornados which is fitted with an ejectable recorder recently lost it because of a spurious signal from the heat sensor. However the radio beacon on the recorder worked and it was recovered undamaged also the aircraft landed quite safely.

Duration

__________________ opinion is that one hour is adequate for crash investigation purposes. He said that in his experience 20 minutes was the longest time that was necessary, however it is nice to have a whole flight and he agreed that take-off is useful. The RAF have had five fatal accidents in the last two weeks one of them being the helicopter winchmen, in the other four cases it was only the last few minutes of information that was relevant.

Standardisation

__________________ view is that in practice it is unlikely it will be possible to produce equipment however flexible the design is that would be suitable for both transport aircraft and fighter trainer aircraft, his view is that transport aircraft have potential space to accommodate civil equipments. He feels that the RAF and the Navy requirements are much the same. Navy aircraft are somewhat more likely to crash into the sea, the likelihood of this in an RAF aircraft depends on the type of mission, i.e. whether its Air Defence. He feels that both cases can be adequately covered by the use of an ejectable recorder.

NJO Bullock

....

N J O BULLOCK
Project Engineer

APPENDIX H

ANALYSIS OF USN AIRCRAFT CRASHES, NAVAL SAFETY CENTER

DEPARTMENT OF THE NAVY
NAVAL SAFETY CENTER
NAVAL AIR STATION
NORFOLK, VIRGINIA 23511

IN REPLY REFER TO:
11A:gc
3750
Ser 4356
11 DEC 1980

From: Commander, Naval Safety Center
To: Commander, Naval Air Test Center

Subj: Navy/Marine Corps Aircraft Crash Statistics

Ref: (a) NAVAIRTESTCEN ltr ser SY71/375 dtd 5 Nov 1980

Encl: (1) Number of Aircraft
(2) Number of Aircraft Recovered
(3) Number of Aircraft for Which Mishap Cause was Determined
(4) Number of Fatalities
(5) Number of Major or Minor Injuries

1. Enclosures (1) through (5) are forwarded in response to reference (a), with the following comments:

a. Information concerning depth of water and distance from land is not recorded in the data bank mishap record.

b. Information concerning number of aircraft recovered for accident investigation is not readily available and would require manual research of micro film records.

c. Cost of aircraft recovery and investigation is not available. Recommend contacting Commander Naval Sea System Command, Mr. P. Salmon, Autovon 227-7386.

d. P-3, KC-130 and C-2 aircraft have been equipped with FDR's. To date only one accident provided any useful information from the FDR system.

2. The enclosed data are FOR OFFICIAL USE ONLY for mishap prevention and are not to be released to private interests or used for any other purpose without the written permission of Commander, Naval Safety Center.

S. P. DUNLAP
Head, Aircraft Operations and
Facilities Division

Number of Aircraft

ALL NAVY/MARINE AIRCRAFT DESTROYED IN MAJOR ACCIDENTS CRASHED INTO:

	CY 1975		CY 1976		CY 1977		CY 1978		CY 1979		CY 1980(Thru	
Model	Land	Water	Land	Water	Land	Water	Land	Water	Land	Water	Land	Water
A-3						1					1	
A-4	12	4	6	4	10	4	11	5	17	2	14	2
A-5		1										
A-6	3	6	6	2	4	2	4	6	4	5	2	5
A-7	5	9	5	7	3	9	4	8	5	6	2	4
C-1			1		1							1
TC-4	1											
C-117	1							1				
C-118	1				1		1					
EC-130						1						
C-131	1											
E-2	1						1		1			
F-4	6	8	5	11	7	7	4	4	4	8	3	6
F-5					1							
F-8	1	5	4	1	3	1				1		1
F-14	1	3	2	4	3	6	1	9		5	1	3
QF-86									1			
H-1	4		7		5		4	1	9		5	1
H-2		1		1	2	2	1		1	1		2
H-3		2	1			1	3	4	1	2		3
H-46	1	2	4	1	1	2	3	2		3	1	2
H-53	3		2	1	8		4		2	2	2	
H-57	1											
P-3					1		2	2		1	1	
S-2			1		1		1	1				1
S-3							1	2		1		1
T-2	1		1	3	1		1	2	4	1	1	1
T-28	3		1		2	1	1	1	1			
T-33	2											
T-34		1	2		3		1	1	2		4	
T-38							1					
T-39	1				1							
T-44											1	
AV-8	3		2	3	5	4	3		3	1	3	1
OV-10							1					
X-26												
All Models	52	42	50	38	63	41	53	49	55	39	41	34

ENCLOSURE (1)

Number of Recovered

ALL NAVY/MARINE AIRCRAFT DESTROYED IN MAJOR ACCIDENTS CRASHED INTO:

Model	CY 1975 Land	CY 1975 Water	CY 1976 Land	CY 1976 Water	CY 1977 Land	CY 1977 Water	CY 1978 Land	CY 1978 Water	CY 1979 Land	CY 1979 Water	CY 1980 (Thru Aug) Land	CY 1980 (Thru Aug) Water
A-3						1					1	
A-4	12		6	1	10	3	11	1	17	1	14	
A-5												
A-6	3		6	1	4	1	4	1	4		2	
A-7	5	1	5	3	2		4	2	5	1	2	
C-1			1		1							
TC-4	1											
C-117	1											
C-118	1				1		1					
EC-130												
C-131	1											
E-2	1						1		1			
F-4	6	1	5	1	7	2	4	1	4		3	
F-5					1							
F-8	1		4		3							
F-14	1		2	2	3	3	1	2			1	
QF-86									1			
H-1	4		7		5		4	1	9		5	1
H-2				1	2		1		1			1
H-3			1				3		1	1		1
H-46	1	1	4		1	1	3	1		2	1	
H-53	3		2		8		4		2	2	2	
H-57	1											
P-3					1		2			1	1	
S-2			1		1		1	1				
S-3							1	1				
T-2	1		1		1		1	1	4		1	
T-28	3		1		2	1	1		1			
T-33	2											
T-34			2		3		1	1	2		4	
T-38							1					
T-39	1				1							
T-44											1	
AV-8	3		2	2	5	1	3		3	1	3	
OV-10							1					
X-26												
All Models	52	3	50	11	62	13	53	13	55	9	41	3

ENCLOSURE (2)

Number In Which Causal Factors Were Determined

ALL NAVY/MARINE AIRCRAFT DESTROYED IN MAJOR ACCIDENTS CRASHED INTO:

Model	CY 1975		CY 1976		CY 1977		CY 1978		CY 1979		CY 1980 (Thru Aug)	
	Land	Water	Land	Water	Land	Water	Land	Water	Land	Water	Land	Water
A-3						1						
A-4	12	3	6	4	10	2	9	3	16	2	12	1
A-5		1										
A-6	3	4	6	2	3	1	3	5		1	1	4
A-7	5	8	5	5	3	6	2	6	5	4	1	1
C-1					1							
TC-4	1											
C-117	1							1				
C-118	1				1		1					
EC-130												
C-131	1											
E-2	1						1		1			
F-4	6	6	3	9	7	6	4	4	3	5	3	6
F-5					1							
F-8	1	4	3	1	3							
F-14	1	3	2	4	3	6	1	7		4	1	3
QF-86									1			
H-1	4		7		5		3	1	9		5	1
H-2		1		1	2	2	1			1		2
H-3		2	1			1	2	4		2		3
H-46	1	2	4	1	1	2	3	2		3	1	2
H-53	3		2	1	7		3		2	2	2	
H-57	1											
P-3					1		2	1		1	1	
S-2			1		1		1	1				1
S-3							1	1				1
T-2	1		1	3	1		1		4	1		1
T-28	3		1		2	1		1	1			
T-33	2											
T-34		1	2		3		1	1	2		3	
T-38							1					
T-39	1				1							
T-44											1	
AV-8	2		2	3	4	3	2		3		3	
OV-10							1					
X-26												
All Models	51	35	46	34	60	31	43	38	47	26	34	26

ENCLOSURE (3)

Number of Fatalities

ALL NAVY/MARINE AIRCRAFT DESTROYED IN MAJOR ACCIDENTS CRASHED INTO:

Model	CY 1975		CY 1976		CY 1977		CY 1978		CY 1979		CY 1980 (Thru Aug)	
	Land	Water	Land	Water	Land	Water	Land	Water	Land	Water	Land	Water
A-3						2					2	
A-4	3	3	1	1	1	2	4	3	3	4	5	2
A-5		2										
A-6	3	5	3	4	3	2	7	4	7	12	2	5
A-7	1	1	2	5	1	6	1	5	2	2	1	2
C-1			6		3							4
TC-4	9											
C-117								2				
C-118							16					
EC-130						16						
C-131	4											
E-2							5		1			
F-4	1	7	5	9	8	5	2		2	7		4
F-5												
F-8			1							1		1
F-14			4		2	1	1	5		4		2
QF-86									1			
H-1			15				4		4		3	
H-2		2			3	1			5			
H-3		1					8		5			8
H-46	3	5	4	1	1	2	9	6		3		4
H-53	9		4	4	32		7		3		7	
H-57												
P-3					13		8	12		5	7	
S-2					2		2					2
S-3							4	4		2		1
T-2	1							2			1	1
T-28			2			2	1					
T-33												
T-34		2	1		1		1				4	
T-38							2					
T-39	2				5							
T-44												
AV-8	2			1	2	2	1			1	1	1
OV-10							2					
X-26												
All Models	38	28	48	25	77	41	85	43	33	41	33	37

ENCLOSURE (4)

Number B and F Injuries

ALL NAVY/MARINE AIRCRAFT DESTROYED IN MAJOR ACCIDENTS CRASHED INTO:

Model	CY 1975 Land	CY 1975 Water	CY 1976 Land	CY 1976 Water	CY 1977 Land	CY 1977 Water	CY 1978 Land	CY 1978 Water	CY 1979 Land	CY 1979 Water	CY 1980 (Thru Aug) Land	CY 1980 (Thru Aug) Water
A-3												
A-4	6	1	4	2	7	3	1		9		4	
A-5		1										
A-6	7	9	6		2	2	1	6	1			1
A-7	2	3		1	1	2	2	11	1	1		
C-1					2							
TC-4												
C-117	4							7				
C-118					2							
EC-130												
C-131	2											
E-2	2											
F-4	2		3	8	5	2	3			2	2	
F-5												
F-8			1		1							
F-14		4		7	4	2	3	4				1
QF-86												
H-1	2		5		11		5		13		5	
H-2		2										2
H-3		2	4					3				1
H-46		4	12		2	2	2	2				2
H-53	4		3		16		9		10	1	4	
H-57												
P-3								10		9	1	
S-2								2				2
S-3												1
T-2			1	2	1				3			1
T-28	2						1					
T-33												
T-34			3		2						1	
T-38												
T-39												
T-44											2	
AV-8	1		1	1	1				3		2	
OV-10												
X-26												
All Models	34	26	43	21	57	13	27	45	40	13	21	11

ENCLOSURE (5)

APPENDIX I

ACCIDENT RECORDING TIME DISTRIBUTION GRAPH AND NTSB COMMENT LETTER

National Transportation Safety Board

Washington, D.C. 20594

November 3, 1980

Mr. Norman W. Bishop
Normalair - Garrett, Ltd.
56 Heather Hill Lane
Woodcliff Lake, New Jersey 07675

Dear Mr. Bishop:

Thank you for your letter of October 27, 1980.

Regarding the graph you sent, "Accident Recording Time Distribution (Data from National Transportation Safety Board)," whoever collected those data never contacted me or anyone else at NTSB of whom I am aware.

Although the amount of data that appears in NTSB reports is probably reflected accurately in the graph, it does not reflect the amount of data that we actually read and evaluate during an accident investigation. We usually go back to the previous takeoff and/or landing, since these data prove to be valuable references. When parameters are behaving abnormally during an accident scenario, the question becomes: "Is it because the DFDR is <u>not</u> working properly or because an accident is happening?" This question can be answered with certainty only if prior takeoff and landing data are available for "calibration purposes."

Although NTSB recommendation letter A-78-27 through 29 calls for a recorder of 10-15 minutes duration, it has been our experience that it is necessary to have a DFDR record of the last takeoff and landing prior to the accident, as well as a record of the preflight exercise of flight controls to maximum deflection. Since microprocessors permit recording of the prior takeoff and landing data on a selective storage basis, the entire time between these events and the accident need not be recorded. Hence, 10-15 minutes of the last data are sufficient, if the prior takeoff, landing, and preflight control exercise are also stored.

The last comment -- some vendors seem to be taking the 10-15 minute figure as an absolute, rather than as a <u>minimum</u>. It has been difficult to convince some tape recorder people that it <u>is</u> okay if they have a 1/2-hour or an hour tape. (Using tape recorders, it doesn't cost anything to do this).

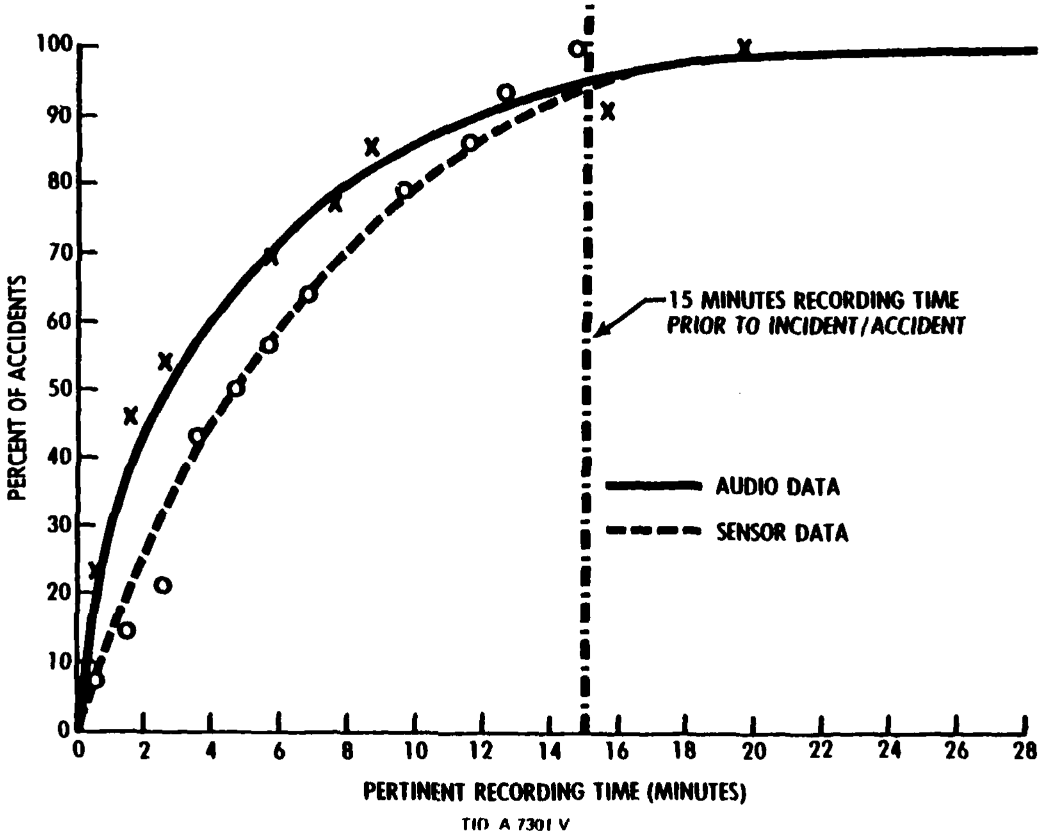
Are you aware that FAA has decided to turn over further development of the TSO on flight recorders to SAE? Perhaps this would be of interest to your organization.

Sincerely yours,

Carol A Roberts

Carol A. Roberts
Chief, Laboratory Services Division

ACCIDENT RECORDING TIME DISTRIBUTION
(DATA FROM NATIONAL TRANSPORTATION SAFETY BOARD)



APPENDIX J

DEVELOPMENT REPORTS ON CRASH PROTECTION TESTS

FIRE PROTECTION TEST

development rep

NORMALAIR-GARRETT LIMITED
YEOVIL SOMERSET ENGLAND BA20 2YD
Telephone Yeovil (Code 0935) 5181
Telex 46132
Telegrams NGL Telex Yeovil

REPORT NUMBER 1305 V DVR12

title Fire Protection Test

part number 1203V000

Prepared by J H Walmsley date 18TH SEPT. 1980
J H WALMSLEY

Checked by John F. Northrop date 7th Oct '80.
J F NORTHROP

Approved by [illegible] date [illegible]
W H JENKINS

period of tests

circulation

full version

Mr D Hooper
Mr W Jenkins
Mr R Strange
Mr J Henshaw
Mr J Northrop
Mr H Edwards
Mr R Thring
Mr V Davies
File

limited version

development repo

summary

customer Bendix Corporation

application F18 recorder

customers specification TSO-C51A

issue number

build standard at receipt

part number 1203V000

issue number -

serial number -

mass

approximate overall dimensions

type approval test schedule number

issue number

N/A

production test schedule number

issue number

N/A

type approval test schedule references

N/A

purpose of test

date of test commencement 11th Sept 1980

conclusion

conclusions

Although the test item was not to the final preferred design of protective cover, i.e. NGL Drg. No. 2002E492, and also had not undergone the preliminary Shock Test and Crush Test, results achieved from this Fire Test and previous Penetration Test lead to the anticipation that this current design of crash protection will meet the requirements of USA Federal Specification TSO-C51A, particularly in view of the extended time of the Fire Test.

development rep

NORMALAIR-GARRETT LIMITED
YEOVIL SOMERSET ENGLAND BA20 2YD

issue number	date	compiled	approved	revision
1	17.9.80	J.H. Walmsley	21/10/80	

Purpose of Test

To carry out a Fire Protection Test to para. 7.8.5 of USA Federal Specification TSO-C51A on a dummy test container made to NGL Worksheet Nos. NWS-4760 and 4761 which had already undergone a Penetration Test to para. 7.8.3 of the same specification for which see NGL Development Test Report No. 1305V DVR11.

Details of Item Tested

The Test container, see Fig. 1, already had a 3/16 inch thick coating on the end face of Chartek 59, an intumescent fire resisting coating supplied by the AVCO Corp. of Lowell, Mass., USA. See Fig. 2.

Prior to fire testing, therefore, similar coats of Chartek 59 were trowelled on to the other four faces to a thickness of 3/16 inch. These also included metal mesh reinforcement, see Fig. 3. This coating was also trowelled over the exposed end flanges to an average thickness of about ¼ inch.

A TTM body assembly with a spool of pre-recorded Kapton tape inside it was positioned inside the test container and held away from it using ¼ inch thick bands of silicone rubber to simulate the effect of the anti-vibration mounts which will be Silicone rubber. Due to the dent caused by the previous Penetration Test, barely 1/16 inch separated the apex of the dent from the TTM body assembly. No actual hole had been pierced in the container and this gap was maintained by a silicone rubber pad and a similar pad was fitted between the TTM body and the base plate, Fig. 4.

Four thermocouples were incorporated into the test assembly. One was welded to the inside of the container on a 4" by 4" face as near to the dent as a welding torch would reach. Another was suspended in the air gap between the container and the TTM body. A third was bolted to the inside metal face of the TTM main body and a fourth was suspended in the air space within the TTM adjacent to the tape.

As a cross check in the case of thermocouple failure during the fire test, a variety of temperature sensitive paints were coated over selected portions of the TTM main body in the tape air space. These permanently change colour if their particular temperature is exceeded. These covered the range 205°C to 400°C.

Prior to assy, a 15 kHz digital signal was recorded on the Kapton tape.

Finally, all reasonable steps were taken to seal the TTM from the surrounding air with the exception, perhaps, of a pinhole leak where two thermocouples emerged from the TTM body.

Details of Test Set-up (Fig. 5 refers)

The test item was placed on a hearth made up of 3 inch thick firebricks. The thermocouples were led out through a gap between the bricks, this gap being filled with dry sand. Further sand was sprinkled over the edges of the flange and baseplate to prevent any flame from impinging directly on the bare metal edges. Further firebricks surrounded three sides of this set-up to contain the heat.

Only two torches were available, one butane, the other propane. These were arranged so that one was aimed at the face directly above the thermocouple welded to it, the other being positioned at 45 degrees downwards so that it heated two faces and one edge, the upper face being that which had suffered the prior penetration test. Fig. 5 shows the arrangement prior to ignition.

The thermocouples were attached to a WATANABE 6 channel potentiometric pen recorder. This recorded in millivolts, the actual temperatures being deduced from standard tables appropriate to the thermocouples metals used. A fifth thermocouple recorded flame temperatures at the start and finish of test about ½ inch from the intumescent coating.

The test was conducted inside a large, draught-free hanger.

Details of Fire Test

The pen recorder was set running, the burners ignited and the time noted. After about 5 minutes the coating had swelled about ⅜ inch where it was directly under the flame and where small areas glowed red. After 15 minutes the coating had not noticeably swelled much more but the size of the incandescent areas had increased. Also, the recorded temperatures inside the TTM had barely reached 90°C so the test was allowed to continue.

After 30 minutes the size of the glowing red areas had further increased but the coating had not swelled any more and the temperature of the thermocouples in the air space adjacent to the tape had reached only 174°C, so the burners were left running.

After 40 minutes it was considered that the test had exceeded the requirements and the burners were turned off after checking that the flame temperatures were both still at 1295°C and that the tape air space temperature had reached 216°C.

The pen recorder was left running for a further 26 minutes to measure the heat soak and temperature run-down during which time the tape air space temperature peaked at 229°C after 47 minutes before slowly reducing to 182°C after 66 minutes. Fig. 6 shows the test in progress at 30 minutes and Figs. 7 and 8 show the test item after test and before strip examination. Fig. 9 shows the time/temperature results achieved, the tape deck metal and tape air space temperatures being too close together over the whole test to be distinguished.

Examination After Test

To reach the nuts holding the base plate it was necessary to cut into the edge of the charred Chartek 59. This proved to be fairly firm to the touch but broke away easily in a light, friable manner when a box spanner was applied. It was noticed that surface cracks had developed in the char within 24 hours of the end of test.

On withdrawing the TTM body from the test container the silicone rubber bands were found to be in good condition although the peak skin temperature had reached 330°C after 40½ minutes. Also the thermocouple had remained welded to the case.

The inside of the test container had turned a light, golden colour in places and was sticky to the touch. Also the outside of the sealed TTM body assy. had turned a dark, golden brown but was not sticky. It is suggested that this might have been due to the cyanoacrylate ester type Loctite used to stick the silicone rubber to the TTM body as an assembly aid.

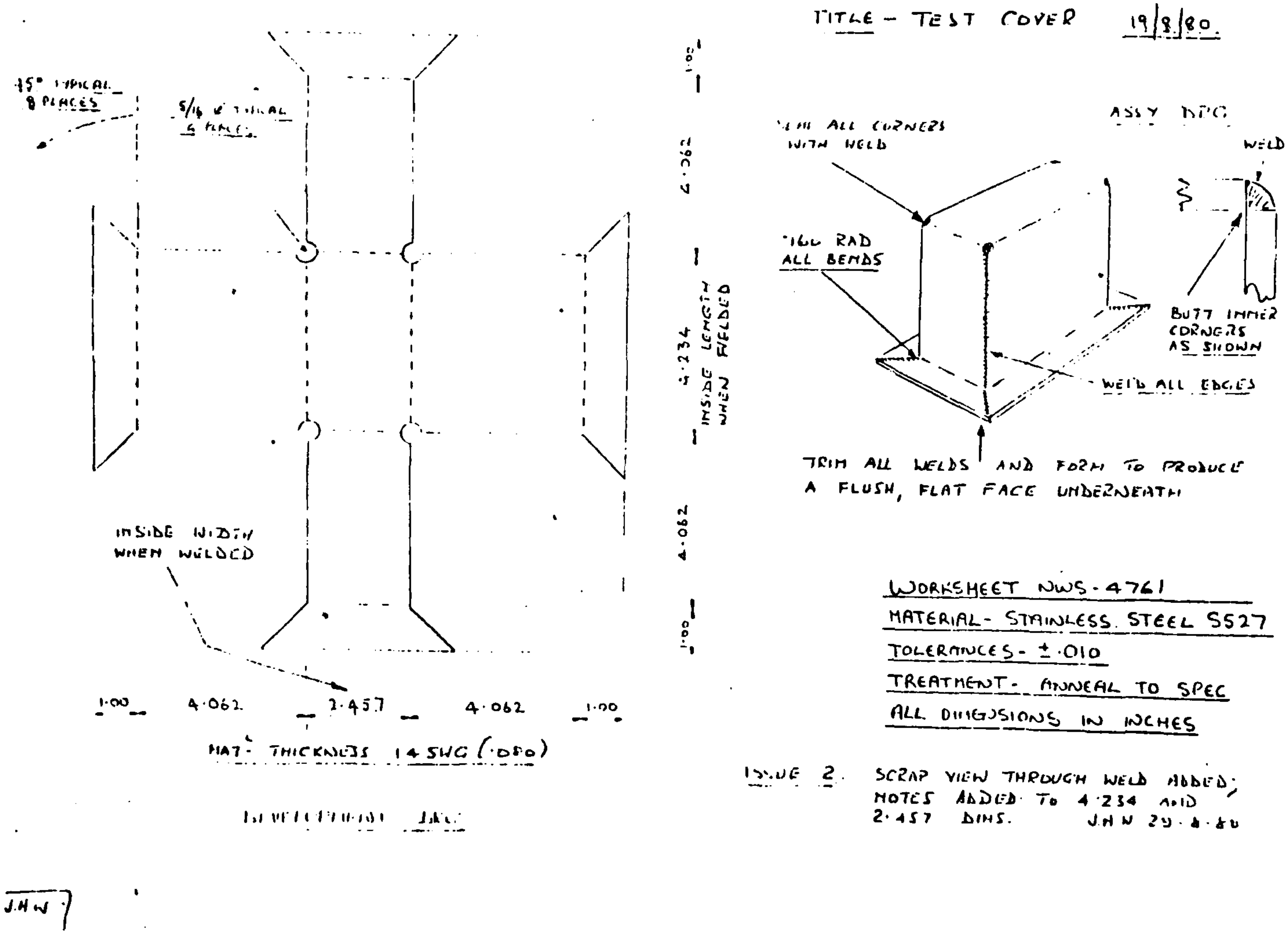
On removing the tape cover, the tape space inside was found to be as clean as before test. Of the five temperature sensitive paints used, one confirmed the peak deck temperature of 228°C, one gave an ambiguous result and the other three were unaffected.

On replaying the tape which had been recorded on a Sony low noise recorder on tracks 1 and 3, it was found that output was low and varied along the tape with the lowest putput on track 3 at about 20 dB loss. Signal transitions were counted before and after test. Of these, 97.7% were recordered from track 1 and 99.7% from track 3. This was achieved using a counter threshold approximately 23 dB below nominal signal level from new tape. Amplitude modulation was present due to variable spacing loss (tape to head). This was due to layer transfer, backing to oxide, which was severe near the centre of the spool. The lowest output was at the inner end of the tape.

The outer layers of tape were in good condition but there was progressive layer to layer adhesion towards the centre of the spool. There was also a fairly uniform transfer of carbon coating to oxide, causing the spacing loss on playback. Removal of carbon coating from the oxide using a solvent (PROPAN-2-OL) over a small section confirmed this, the output increasing over the cleaned section. Pre-conditioning the tape at the comparatively dry value of 30% RH at 20°C for 12 hrs prior to test might have improved the playback performance but this was not carried out in this instance.
Pre-test original output:-
Track 1:- 2750 mV peak to peak
Track 3:- 3300 mV peak to peak
Post-test final output:-
Track 1:- 1400 - 400 mV peak to peak
30% amplitude modulation
Track 3:- 350 - 300 mV peak to peak
20% amplitude modulation

Conclusions

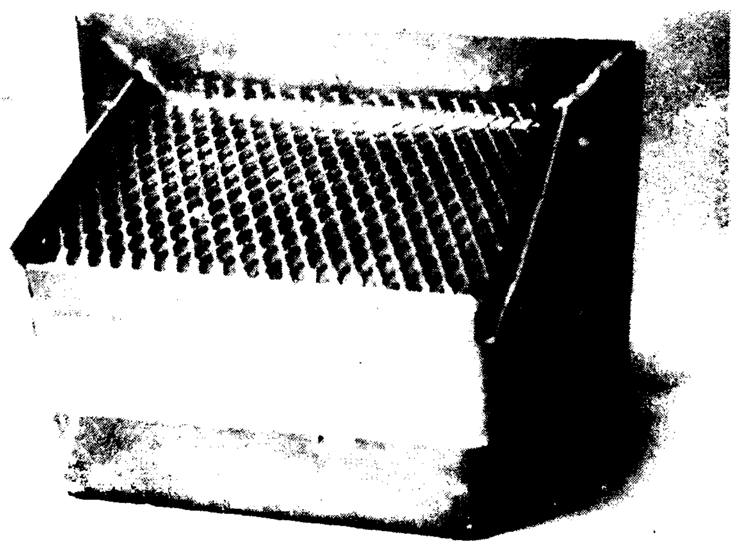
Although the test item was not to the final preferred design of protective cover i.e. NGL Drg No 2002E492, and also had not undergone the preliminary Shock Test and Crush Test, results achieved from this Fire Test and previous Penetration Test lead to the anticipation that this current design of crash protection will meet the requirements of USA Federal Specification TSO-C51A particularly in view of the extended time of the Fire Test.



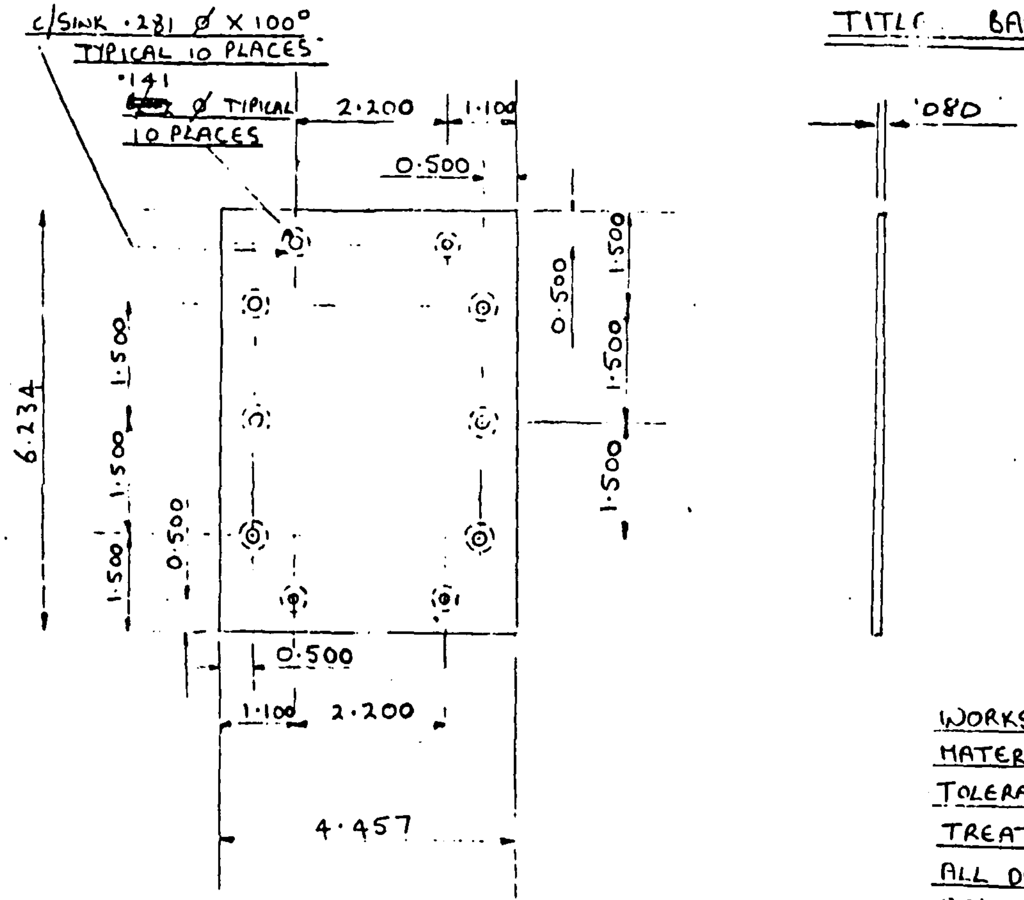
TITLE - TEST COVER 19/8/80.
ASSY DPG
SEAL ALL CORNERS WITH WELD
WELD
·160 RAD ALL BENDS
BUTT INNER CORNERS AS SHOWN
WELD ALL EDGES
TRIM ALL WELDS AND FORM TO PRODUCE A FLUSH, FLAT FACE UNDERNEATH
WORKSHEET NWS-4761
MATERIAL - STAINLESS STEEL S527
TOLERANCES - ±·010
TREATMENT - ANNEAL TO SPEC
ALL DIMENSIONS IN INCHES
ISSUE 2. SCRAP VIEW THROUGH WELD ADDED; NOTES ADDED TO 4·234 AND 2·457 DIMS. J.H.W 29·8·80
45° TYPICAL 8 PLACES
5/16 Ø TYPICAL 4 PLACES
1·00
4·062
4·234 INSIDE LENGTH WHEN WELDED
INSIDE WIDTH WHEN WELDED
1·00
4·062
2·457
MAT: THICKNESS 14 SWG (·080)
J.H.W

FIG 1

FIG 2



TITLE BASE PLATE 11/8/80



WORKSHEET.- NWS 4760
MATERIAL.- STAINLESS STEEL 5527
TOLERANCES.- ± .010
TREATMENT - NONE
ALL DIMENSIONS IN INCHES
SCALE - 1/2

FIG 4

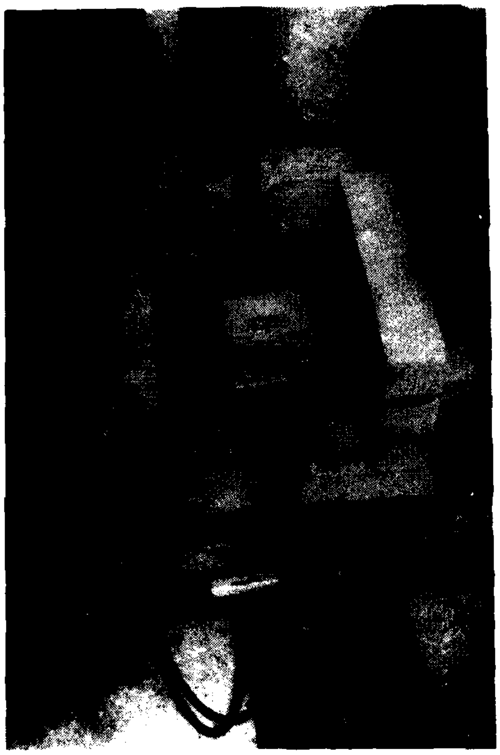


FIG 5

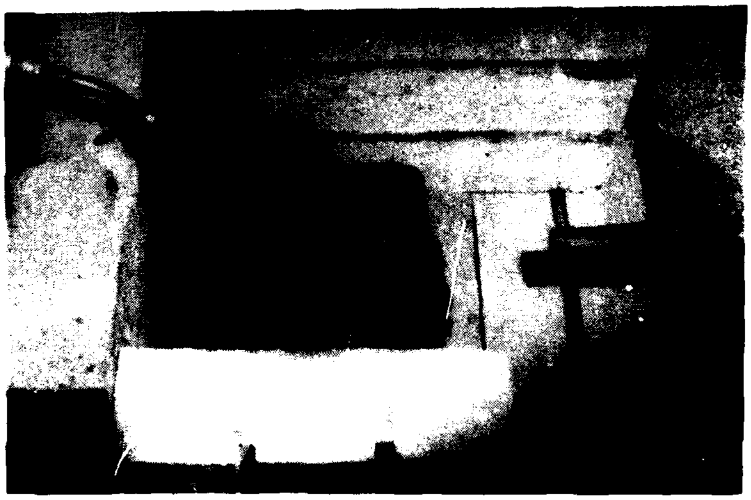
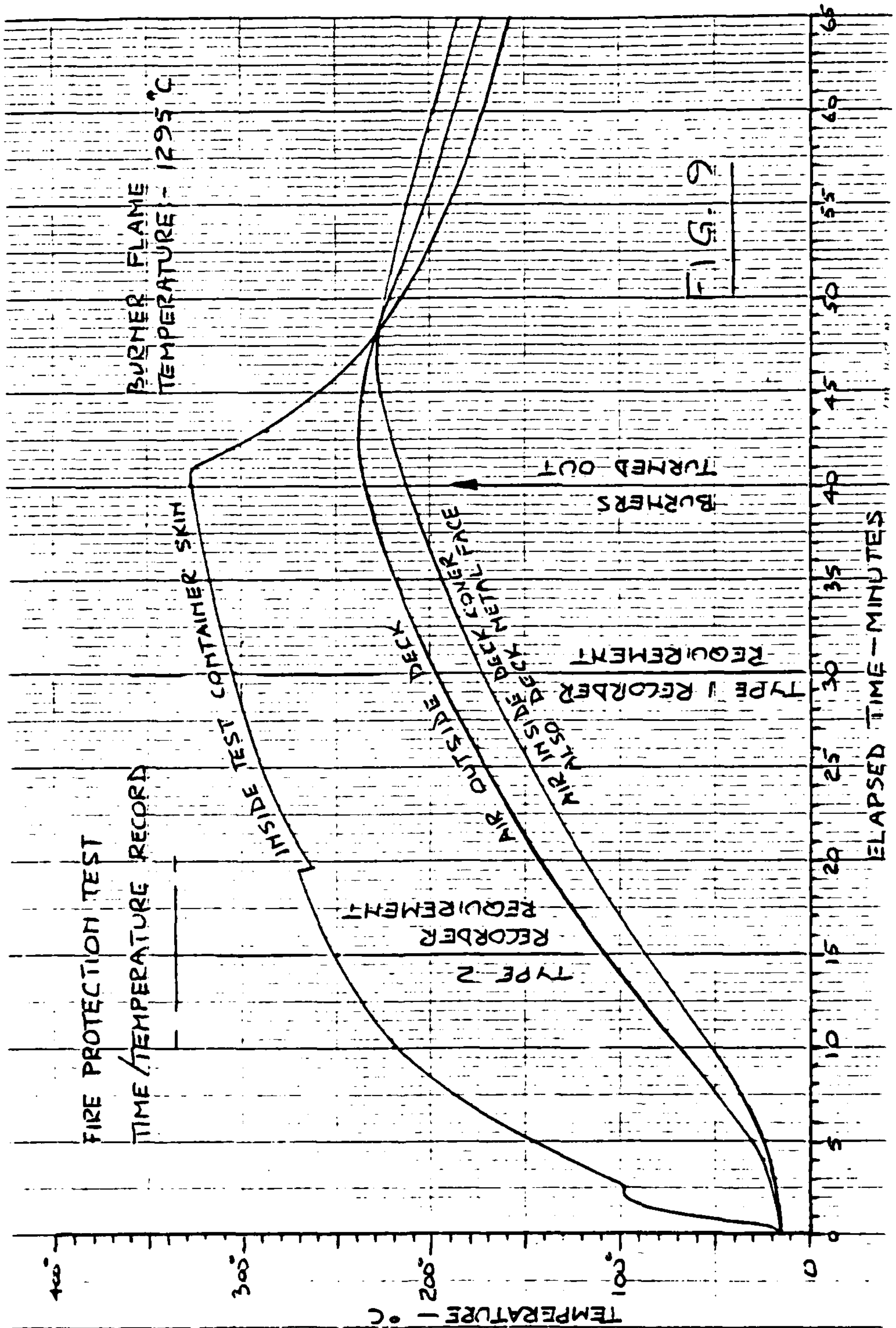


FIG 6

FIG 7

FIG 8


FIRE PROTECTION TEST
TIME/TEMPERATURE RECORD
BURNER FLAME TEMPERATURE - 1295°C
FIG. 9
INSIDE TEST CONTAINER SKIN
AIR OUTSIDE DECK
AIR INSIDE DECK CORNER
ALSO DECK METAL FACE
TYPE 2 RECORDER REQUIREMENT
TYPE 1 RECORDER REQUIREMENT
BURNERS TURNED OUT
ELAPSED TIME—MINUTES
TEMPERATURE — °C
0
100
200
300
400
5
10
15
20
25
30
35
40
45
50
55
60
65

PENETRATION TESTS

development rep

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REPORT NUMBER 1305 V DVR11

title Penetration Tests

part number 1203 V 000

Prepared by _S Bartlett_ date 17/9/80
S BARTLETT

Checked by _J.H. Walmsley_ date 17/9/1980
J H WALMSLEY

Approved by ______ date ______
W H JENKINS

period of tests 4th September 1980

circulation

full version

limited version

Mr D Hooper
Mr W Jenkins
Mr R Strange
Mr J Henshaw
Mr J Northrop
Mr J Walmsley
Mr V Davies
Mr H Edwards
File

development repo

summary

customer Bendix Corporation

application F18 Recorder

customers specification TSO-C51A

issue number

build standard at receipt

part number 2002 E 492

issue number —

serial number —

mass

approximate overall dimensions

type approval test schedule number

issue number

N/A

production test schedule number

issue number

N/A

type approval test schedule references

N/A

purpose of test To carry out penetration resistance tests to paragraph 7.8.3 of the USA Federal Specification TSO-C51A, on two dummy test cases, generally to NGL drawi number 2002E492. These were made to NGL worksheet numbers NWS 4760 and NWS 4761.

date of test commencement 4th September 80 conclusion 5th September 80

conclusions

The case design is adequate to satisfy the requirements of the penetration test. As regards the fire test still to be carried out, no open hole was caused by the spike, neither did the case split and the fire protecting intumescent paint remaine intact with no cracks.

NORMALAIR-GARRETT LIMITED
YEOVIL SOMERSET ENGLAND BA20 2YD

issue number	date	compiled	approved	revision
1	11.9.80	[signature]	[signature] 24/10/80	

Penetration Tests

Purpose of test

To carry out penetration resistance tests to paragraph 7.8.3 of the USA Federal Specification TSO-C51A on two dummy test cases, generally to NGL drawing number 2002E492. These were made to NGL worksheet numbers NWS 4760 and NWS 4761.

Test set up

The drop tower used was of British Aerospace manufacture and comprised a rail-guided circular carriage about 30 inches in diameter. This could be raised to any desired height up to about 20 feet and was released electrically by a standard bomb release hook.

The test cases were in turn placed on a bed of dry sand to Specification DEF-133 paragraph 10.2. This sand is essentially similar to that known as Redhill 65, supplied by British Industrial Sand Ltd, Stoke on Trent, Staffordshire, which was preferred but not available. It was contained in a 50 gallon oil drum which was approximately 24 inches diameter by 24 inches deep.

The USA Federal Specification TSO-C51A paragraph 7.8.3 calls for a 500 lbs weight steel bar to be dropped from a height of 10 feet, with the point of contact having an area not greater than .05 square inches (0.252 diameter). This gives an impact energy of 500 x 10 = 5000 ft lbs. The carriage and spike used weighed a total of 639 lbs, so to maintain the same impact energy, the carriage was dropped from a height of 5000/639 feet = 7.825 feet. The impact spike used is shown in Fig 1 and was screwed into a 2 inch diameter by 10 inches long mild steel bar extending downwards from the carriage.

Both still and high speed cine photography at 400 frames per second were available and these were both used before, during and after each test.

Test Details

The test assembly used for Tests 1 and 2 contained a TTM, within which were two tape spools mounted on shafts, together with a full length of Kapton tape wound on one spool, about 2 feet of the free end being wrapped round stand-off bolts and fastened to the empty spool, thus duplicating the "end of tape" condition. Prior to test a digital signal was written on tape tracks 1 and 3, (of 3237 flux changes per inch) this being equal to a 15 KHz signal at normal recording speed used in the F18 system. The TTM was held in the centre of the surrounding test casing by 3/16 inch thick expanded polyurethane foam, to simulate the effect of the anti-vibration mounts. On the outside of the test case a 3/16 inch thick layer of intumescent paint, "Chartek 59" with expanded metal reinforcement, (see Fig 2) was applied to the face chosen to be subjected to the penetration test. The impact point chosen for the test was estimated to produce the maximum possible tape damage, and was marked on the outer case with a red X.

The test assembly used for Test 3 contained a solid aluminium alloy block 1 inch shorter than the inside depth of the case. This block was located in the centre of the case volume by 3/16 inch thick foam round the sides and by 3/8 inch thick foam at the ends in the direction of impact. This 1 inch dimension was chosen as being the approximate amount the real case could be expected to deform by crushing the comparatively weak latch and connector assemblies before meeting the solid TTM case, thus preventing further deformation. This case also had a 3/16 inch thick layer of intumescent paint with expanded metal reinforcement over the chosen impact area, see Fig 3.

Fig 4 shows a general view of the test rig prior to test.

<u>Test Results</u>

<u>Test 1</u>

See Figs 5, 6 and 7. These show that the spike, which was aimed towards one side of the case, simply tipped it over in the sand and then slid past, being brought to rest by the top of the 50 gallon oil drum which was considerably deformed as will be seen in Fig 6. The test item merely suffered a slight dent and the local removal of intumescent paint down to the expanded metal reinforcement.

<u>Test 2</u>

Test 1 was declared invalid as the object of the test was to find out just how much damage the case could sustain without loss of ability to recover tape data. To this end a 1/2 inch thick by 4 inches by 7 inches steel plate was interposed between the test case and the sand, with the spike aiming point at the centre of this area, to prevent the test case from tipping over again. Test 1 was then repeated and results are shown in Figs 8, 9, 10, 11, 12 and 13. From these it will be seen that the spike did not penetrate the steel cover but produced a local dent in the tape spool. When the tape was subsequently replayed it was found that the indentation of the reel flanges causing deformation of the tape pack once per revolution, gave a momentary reduction of signal level of 11 dB. The duration of the effect where the signal was below 95% of its normal value was 50 ms at a tape velocity of 7.5 IPS. The tape was played back on the identical equipment used for writing the initial signal. This comprised a twin capstan transport with an intercapstan tension of 3.5 oz (0.97N), using the edge track. Reduced drop out depth could be achieved using much higher tension in the tape but a special tape transport would be required for this purpose. The 11 dB drop out is caused purely by head to tape contact effects. Pre-annealing the tape at high temperature may stress relieve the deformed portions. This is another method of improving the performance of a damaged tape. Figs 14 and 15 show photographs of a typical normal tape and the section of deformed tape from the tape spool used during the penetration test.

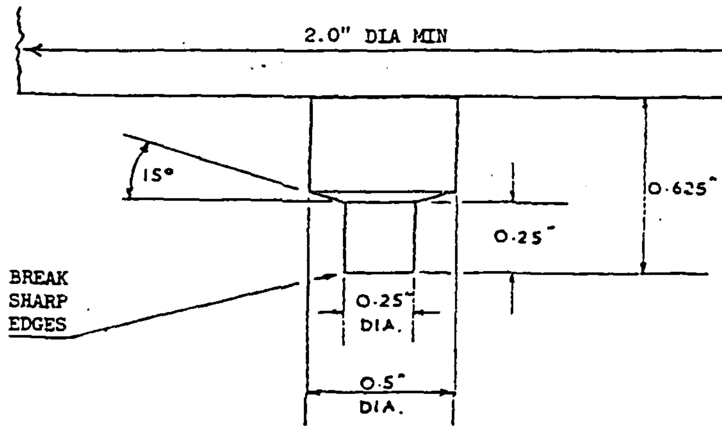
<u>Test 3</u>

In this test, the case was expected to crumple, leaving the TTM intact. Figs 16, 17, 18, 19, 20 and 21 show that slight bulging at the sides occurred together with a deep dent in the penetrated face, which was pushed in approximately 3/4 inch. The spike did not puncture the test case, but caused a slight dent in the solid Aluminium block. See Figs 22 and 23 . Fig 24 shows the condition of the S-130 steel impact spike after completion of the above 3 tests. Fig 25 shows an Approved Test House Certificate for the 3 tests carried out and was issued by British Aerospace.

Conclusion

The case design is adequate to satisfy the requirements of the penetration test. As regards the subsequent fire test, still to be carried out, no open hole was caused by the spike, neither did the case split and the fire protecting intumescent paint remained intact with no cracks.

Normalair-Garrett Limited
NJOB/BRB/486
26th August 1980



MATERIAL:- STAINLESS STEEL S-130

IMPACT SPIKE.
PENETRATION RESISTANCE TEST.

FIG 1

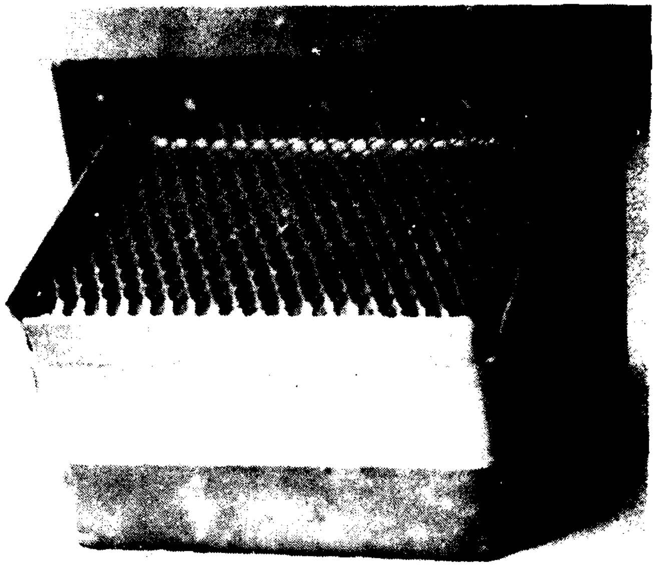
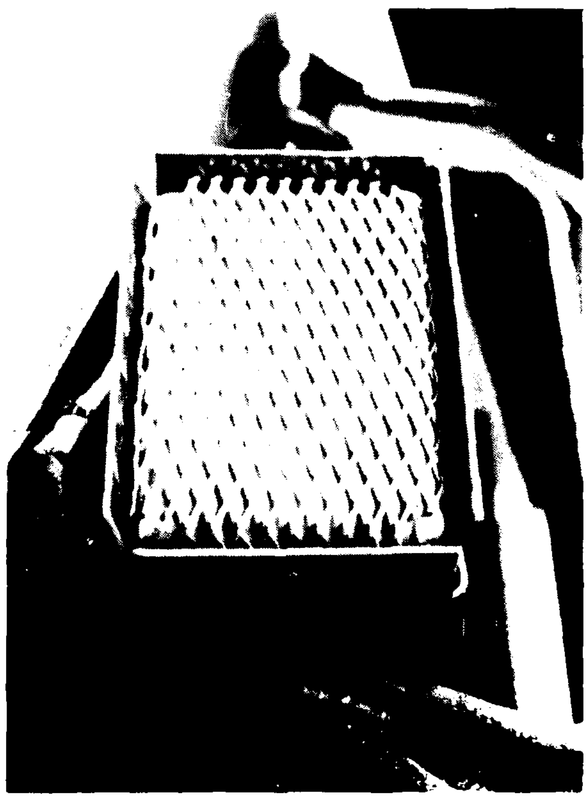


FIG 2



AD-A101 503 AIRESEARCH MFG CO OF CALIFORNIA TORRANCE F/G 14/3
CRASH SURVIVABLE FLIGHT DATA RECORDING SYSTEM STUDY.(U)
JUN 81 F33615-80-C-0135
UNCLASSIFIED 81-17693 ASD-TR-5011 NL

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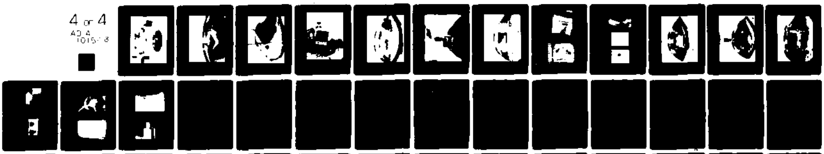

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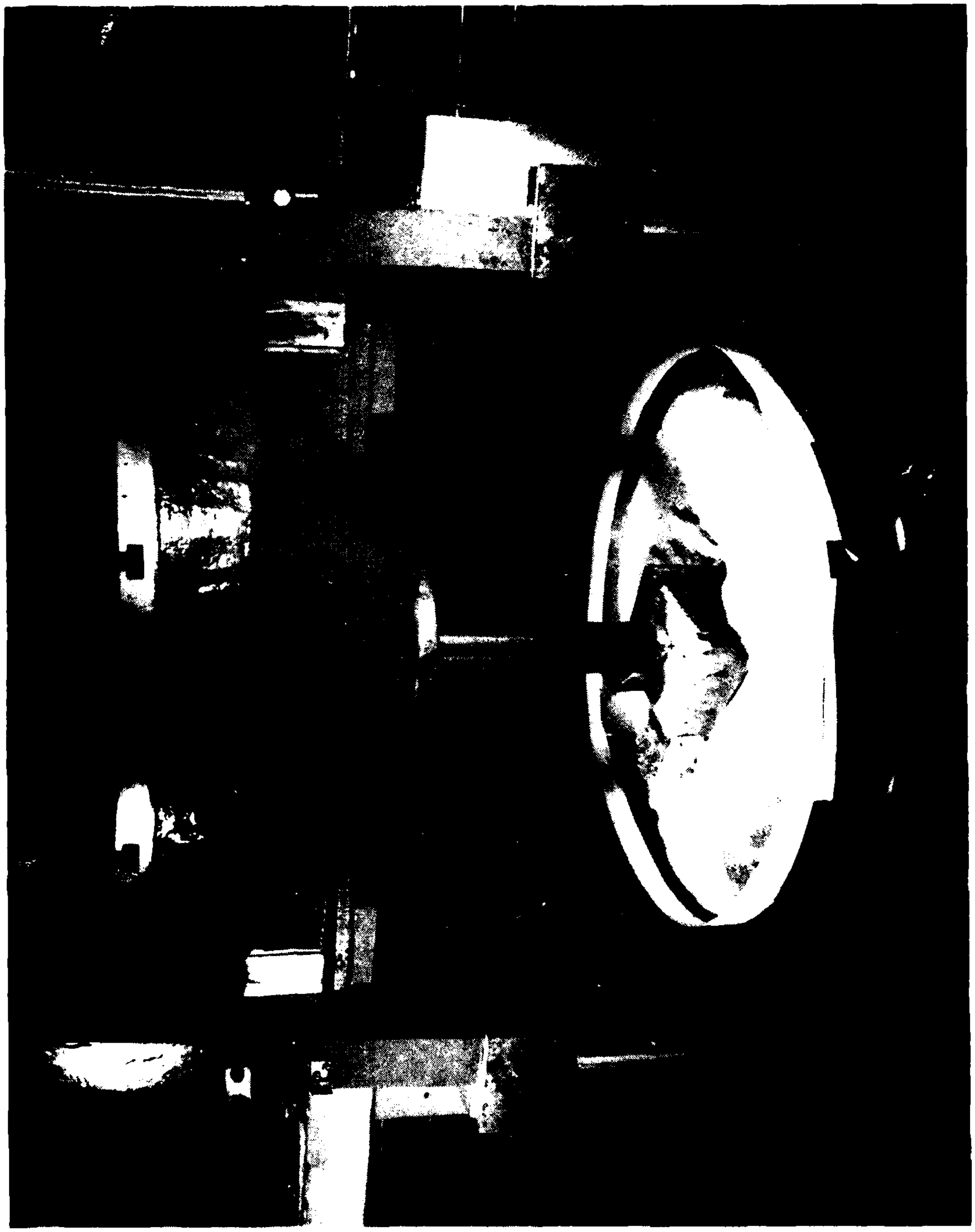

FIG 4

F-33787

F-33788

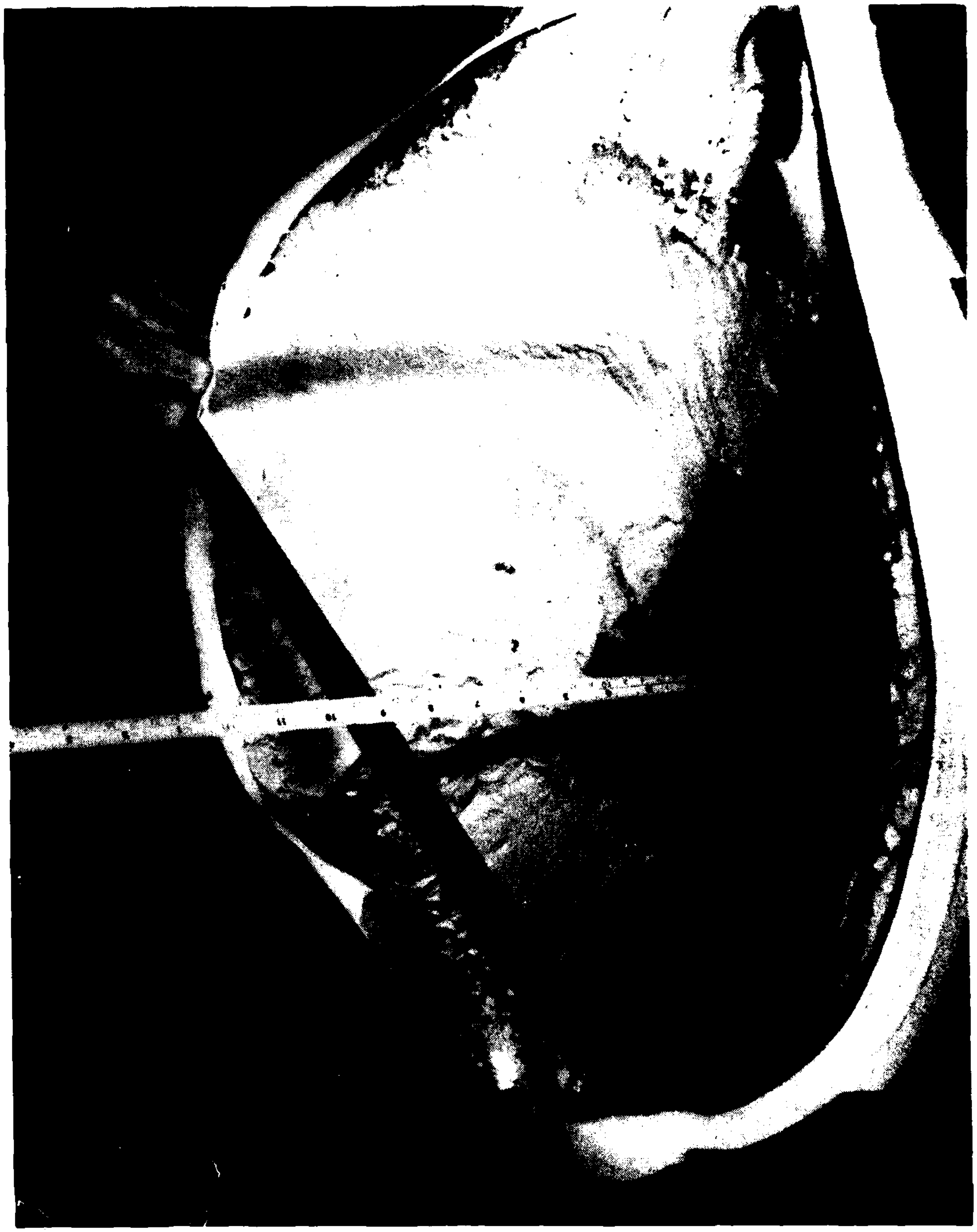

FIG 6

F-33789

FIG 7

F-33790

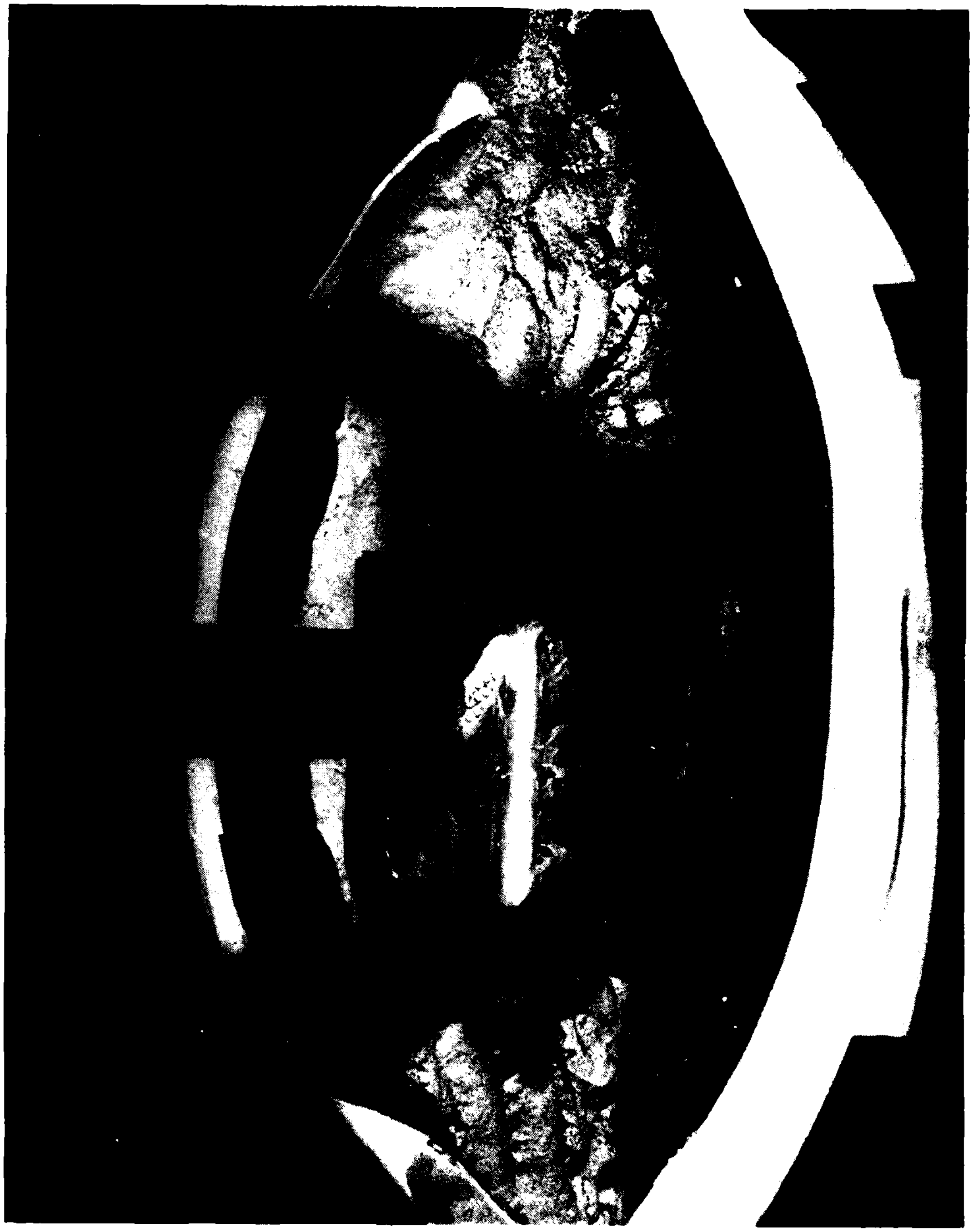

FIG 8

F-33791

FIG 9

F-33792

FIG 10

F-33793

FIG 11

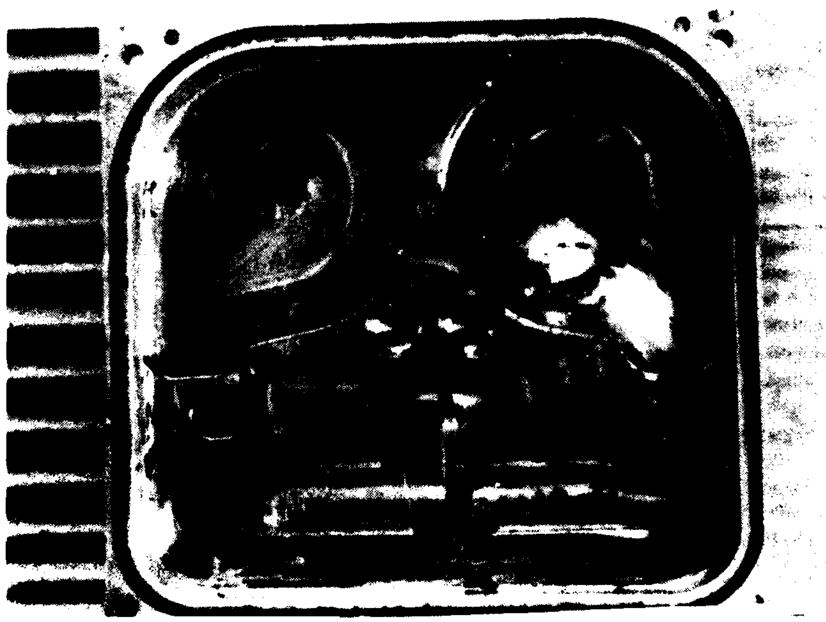

FIG 12

F-33794

FIG 13

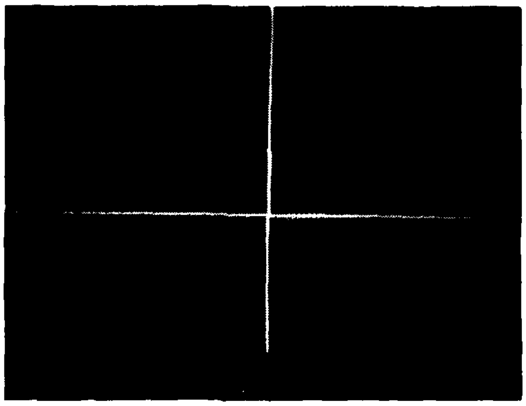

FIG 14

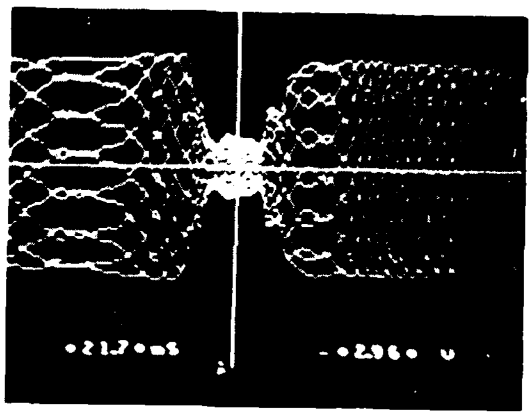

FIG 15

F-33795

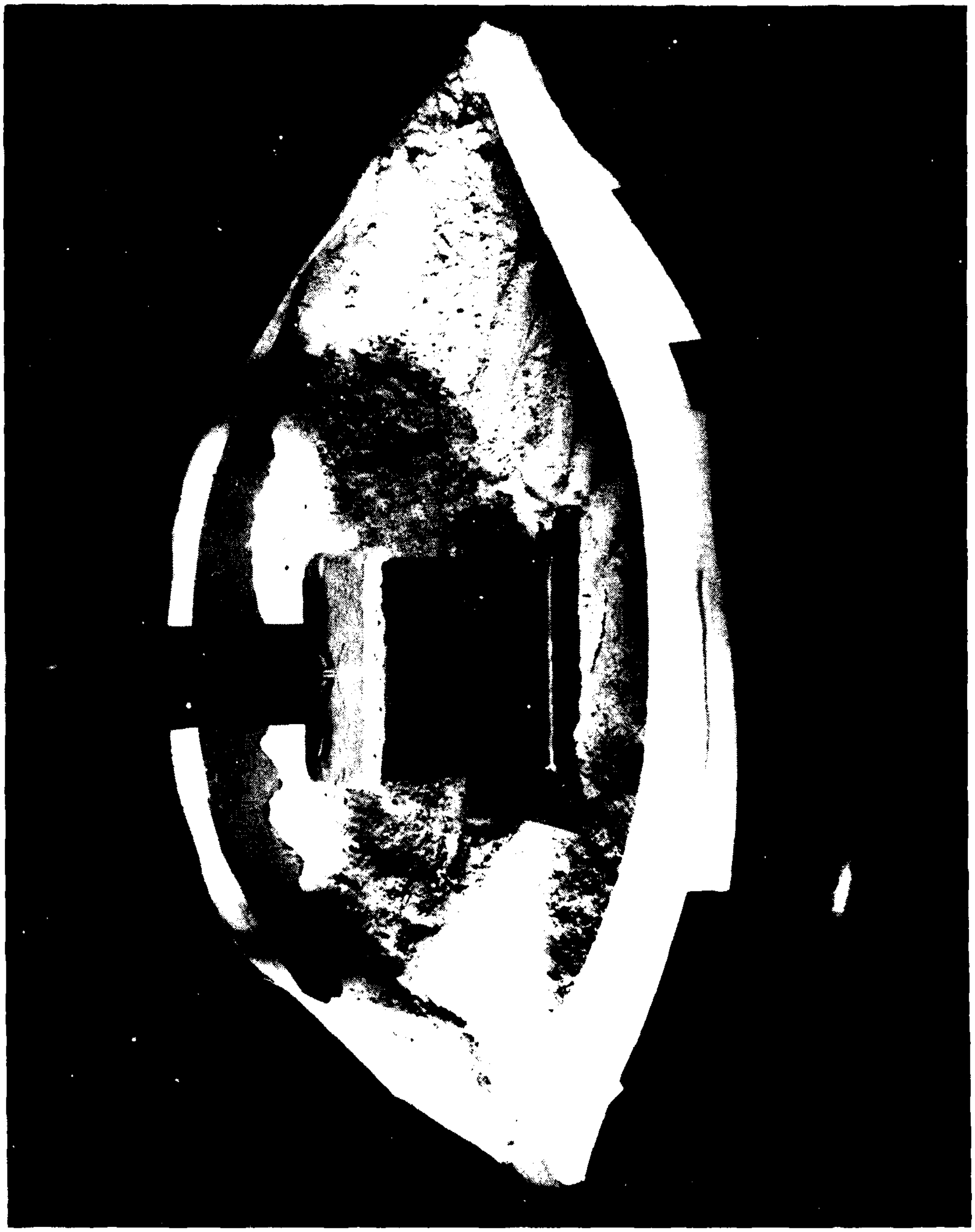

FIG 16

F-33796

FIG 17

FIG 18

F-33798

FIG 19

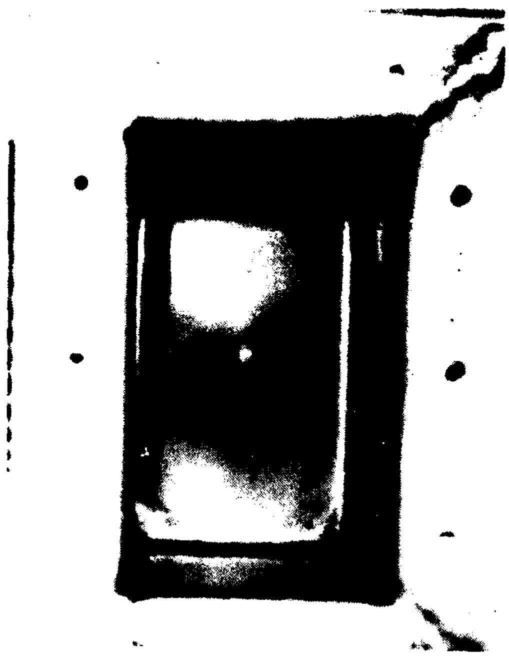

FIG 20

F-33799

FIG 21

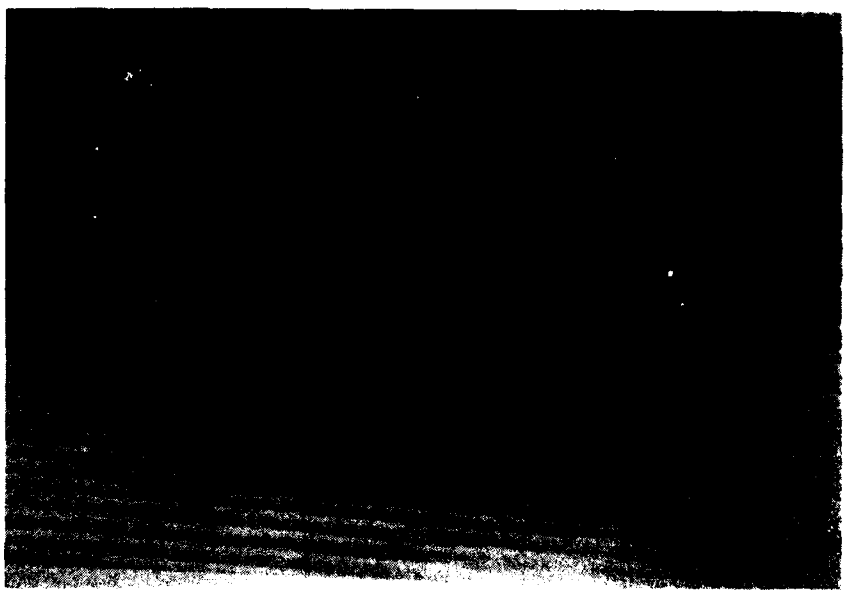

FIG 22

F-33800

FIG 23

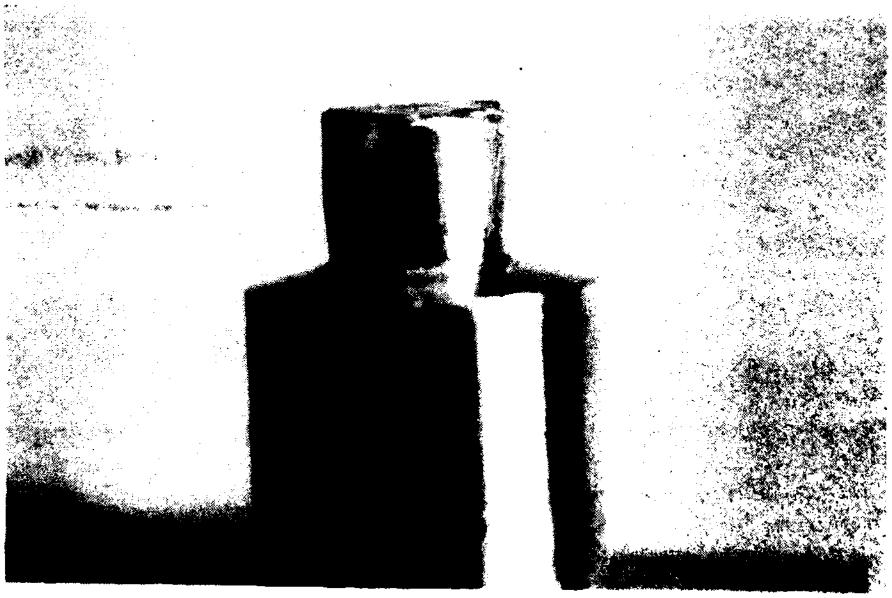

FIG 24

F-33802

British Aerospace
DYNAMICS GROUP
STEVENAGE - BRISTOL DIVISION
SIX HILLS WAY, STEVENAGE, HERTS

APPROVED CERTIFICATE
Nº 94

Approved Test House Certificate

CUSTOMER Normalair-Garrett Ltd., YEOVIL SOMERSET BA202YD. For the attention of Mr.J. Walmsley	ENVIRONMENTAL ENGINEERING LABORATORY DEF. STAN 05-32 APPROVAL No. 20JB 15		REPORT No.
TITLE OF EQUIPMENT OR COMPONENT	SERIAL NUMBER(S) OF ITEM(S)	TEST PROGRAMME	SPECIFICATION
Flight Recorder, 12037.	Test Unit 1	Drop test on to the equipment using a ¼" dia. spike (To drawing No. 1JOB/BRB/406) from a height of 7.025ft. using a carriage weight of 539lb. The equipment was placed on a 2ft. depth of sand in a container 9ft in diameter.	US FEDERAL SPECIFICATION TSO-C51 A PARA.7.8.3.

REMARKS The sand used for the test was that specified in DEF.133 Clause 102. Photographs taken before during and after the test both still and cine will be supplied as soon as possible. On completion of the test the equipment was returned to Normalair Garrett Ltd. for analysis.

Certified that the tests have been conducted in accordance with the requirements of DEF STAN 05-32.

SIGNED ....

FOR AND ON BEHALF OF
BRITISH AEROSPACE DYNAMICS GROUP

F 7641 3/001 (8-79)

DATE 3/9/80

HIGH-TEMPERATURE TAPE TESTS

development rep

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REPORT NUMBER 13057 DVR13

title High Temperature Tape Tests

part number

Prepared by ______________________ date 24/10/80

S BARTLETT

Checked by ______________________ date 24/10/80

J F NORTHROP

Approved by ______________________ date

W H JENKINS

period of tests 12th August to 16th August 1980

circulation

full version

Mr D Hooper
Mr R Strange
Mr J Henshaw
Mr W Jenkins
Mr C Ross
Mr J Northrop
Mr M Lock
Mr K Edwards

limited version

development repc

summary

customer

application F18 Recorder

customers specification

issue number

build standard at receipt

part number

issue number

serial number

mass

approximate overall dimensions

type approval test schedule number

issue number

N/A

production test schedule number

issue number

N/A

type approval test schedule references

N/A

purpose of test To discover the highest soak temperature after which recorded data may still be recovered from Graham Thermo 465 Kapton based and Ampex 797 Mylar bas recording tapes.

date of test commencement 12.3.80

conclusion 16.8.80

conclusions

On all the samples of Kapton and Mylar recording tapes, tested up to 300°C for Kap and 120°C for Mylar, the recovery of data has increased significantly compared wit the previous tests covered in Development report 1305VDVR9.

development rep

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issue number	date	compiled	approved	revision
1	24.10.80		27.10.80	

Purpose of tests

To discover the highest soak temperature after which recorded data may still be recovered from Graham thermo 465 Kapton based and Ampex 797 Mylar based recording tapes. Tests on Mylar tape were carried out to cover the possibility of Kapton tape becoming unavailable in the future. These tests are a continuation of the initial high temperature tests covered by Development Report 1305V DVR9.

Test set up

Kapton tape Test No. 1 (tapes A and B)

Two fully loaded spools of Kapton recording tape, each having a digital signal at 3200 FCI written on tracks 2 and 4, were fitted onto spool shafts inside a dummy TTM body. Two thermocouples were fed into the sealed body through a sealing plate and were attached to the spool hubs to monitor the correct temperature inside the TTM. The assembly was then placed inside an oven, the temperature being raised from ambient to 400°C as quickly as possible and allowed to stabilise for 1 hour. The oven was then switched off and the assembly allowed to cool back to ambient. Both tapes were replayed in an attempt to recover the data. Results are recorded.

Oven time/temperature graph for Kapton tape tests is shown in Fig 1.

Mylar tape Test No. 2 (tape E)

Using only 1 fully loaded spool of Mylar recording tape, test 1 was repeated. Mylar tape has a polyester base and tends to change properties at high temperatures. Accordingly the tests on Mylar tape were conducted at a lower temperature. The temperature was raised from ambient to 140°C then allowed to stabilise for 1 hour, before being allowed to cool back to ambient. The tape was then replayed to try and recover the data. Results are recorded.

Oven time/temperature graph for Mylar tape tests is shown in Fig 2.

Test No. 2 was repeated using another fully loaded spool of Mylar recording tape (tape D) but, for this test, the soak temperature was limited to 110°C. After cooling to ambient, the tape was again replayed for data recovery. Results are recorded.

Kapton tape Test No. 3 (tape C)

A third loaded spool of Kapton recording tape with the same digital signal used in the previous tests was placed into a circular Aluminium alloy sealed housing, simulating the inside air volume of a TTM. A thermocouple was fed through a small hole in the top of the housing and attached to the spool hub for temperature readings inside the test housing. The housing was placed inside an oven, the temperature being raised from ambient to 300°C and then allowed to stabilise for 1 hour. The housing was then allowed to cool, after which data recovery was carried out. Results are recorded.

Mylar tape Test No. 4 (tape F)

Using a third loaded spool of Mylar recording tape, test 3 was repeated with the soak temperature limited to 120°C. After cooling to ambient data recovery was carried out. Results are recorded.

Equipment

1. 6049K TTM Test Set
2. Universal Counter, Racal Type 835
3. Attenuator, Marconi Instruments Ltd Type TF-2162
4. Oscilloscope, Gould Type OS-3500
5. Digital Thermometer, Comark Type 5000, 10 way.
6. Oven with circulating fan. AEW London 6.6 KW. 500°C maximum.
7. Spectrum Analyser. Hewlett-Packard Type 35 FOA.

Test Results

Pre-heat test measurements

Tape	Track 2 Read Amp Output Volts P-P	Track 4 Read Amp Output Volts P-P
Kapton A	3.45	3.85
Kapton B	3.20	3.60
Mylar D	3.37	3.97
Mylar E	3.40	3.95

Post heat test measurements

Tape	Track 2 Read Amp Output Volts P-P	Track 4 Read Amp Output Volts P-P
Kapton A	0.6	0.65 - 0.7
Kapton B	0.4	0.4
Mylar D	3.0 - 3.1	3.57
Mylar E	3.15	3.60

Pre-heat test measurements

Tape	Track 2 Read Amp Output Volts P-P	Track 2 Complete Cycles Count	Track 4 Read Amp Output Volts P-P	Track 4 Complete Cycles Count
Kapton C	2.4	1785940	2.9	17-011
Mylar F	5.0	191985	7.5	196793

Post heat test measurements

Tape	Track 2 Read Amp Output Volts P-P	Track 2 Complete Cycles Count	Track 4 Read Amp Output Volts P-P	Track 4 Complete Cycles Count
Kapton C	1.25	29441	1.5	65382
Mylar F	4.5	191920	5 - 7.5	196693

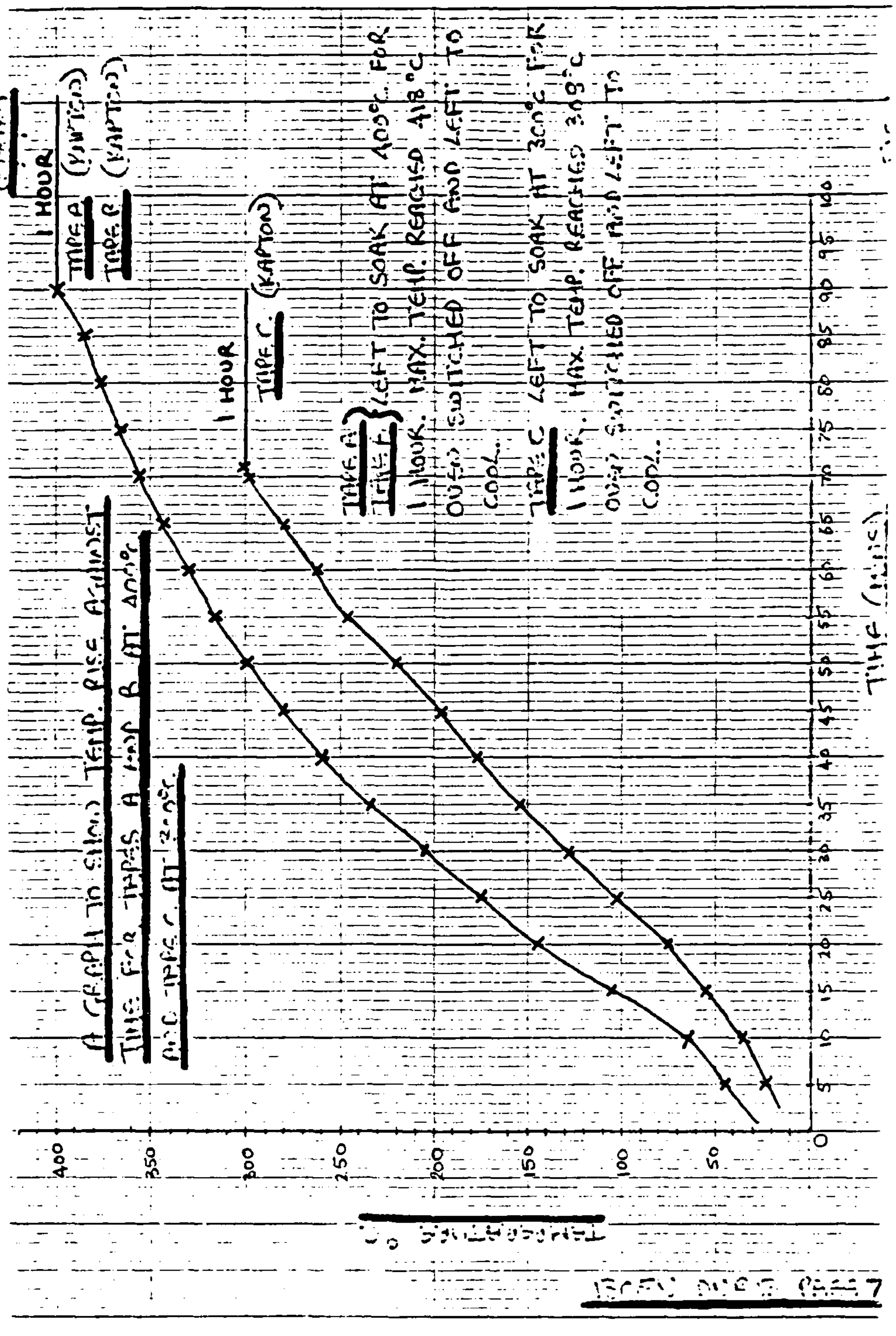
Summary

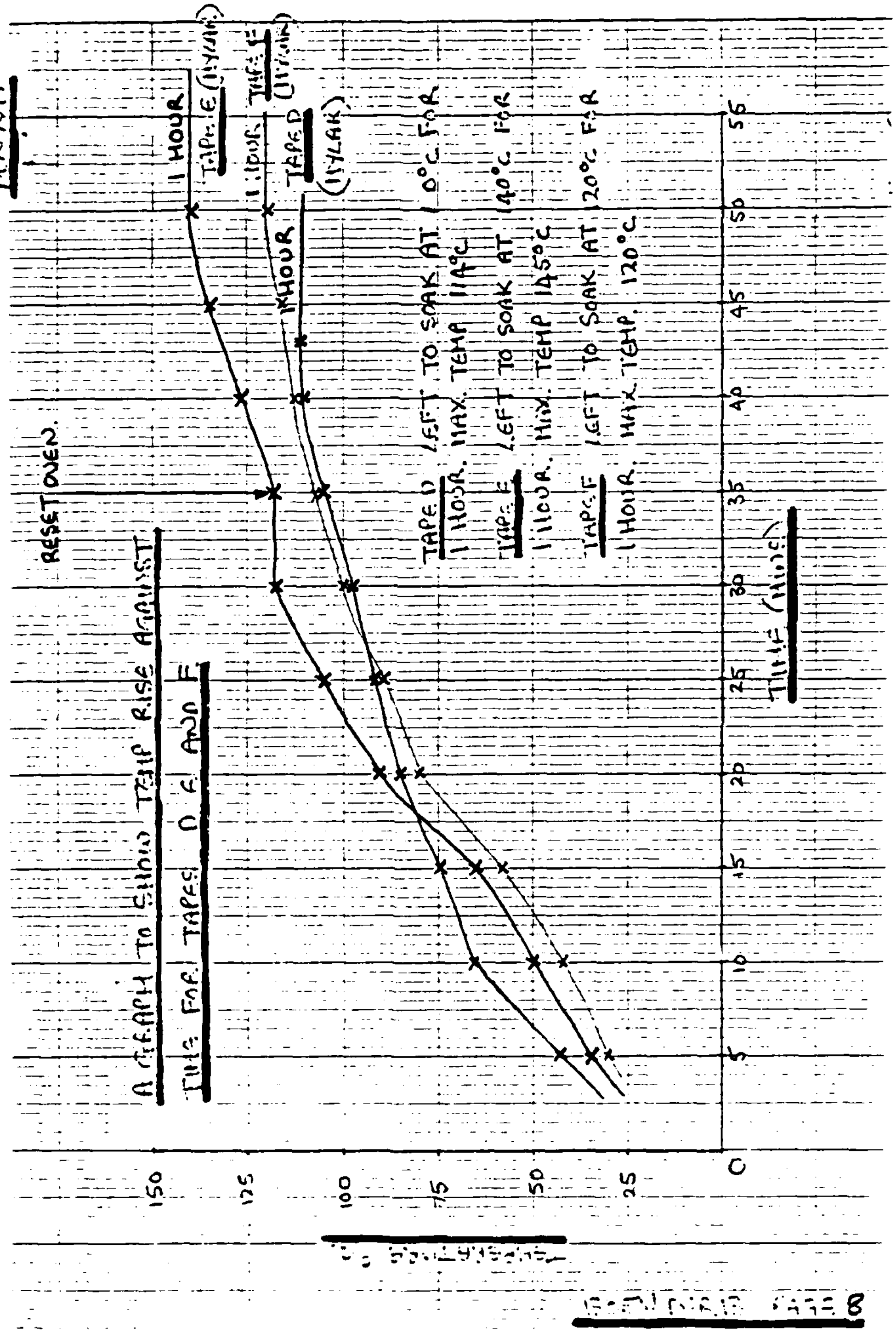
Beginning with the 3 samples of Kapton recording tape, all 3 had a good physical appearance and produced a clean signal. The signal loss of the sample heated at 300°C was 48%, compared with 84% and 89% on the samples heated at 400°C. One sample heated at 400°C showed severe dropouts and amplitude modulation which deteriorated in the last half of the tape.

The 3 samples of Mylar tape again had a good physical appearance with a clean signal. There were no severe dropouts in any of the samples although all 3 suffered from amplitude loss due to a slight tape weave. This was more noticeable on the last tape sample heated at 140°C which also suffered from severe layer to layer adhesion in the last 10% of the tape pack.

Conclusion

On all the samples of Kapton and Mylar recording tape, tested up to 300°C for Kapton, and 120°C for Mylar, the recovery of data has increased significantly compared with the previous tests covered in Development report 1305V DVR9.


A GRAPH TO SHOW TEMP. RISE AGAINST TIME FOR TAPES A AND B AT 400°C AND TAPE C AT 300°C.
1 HOUR
TAPE A (KAPTON)
TAPE B (KAPTON)
1 HOUR
TAPE C (KAPTON)
TAPE A / TAPE B LEFT TO SOAK AT 400°C FOR 1 HOUR. MAX. TEMP. REACHED 418°C OVEN SWITCHED OFF AND LEFT TO COOL.
TAPE C LEFT TO SOAK AT 300°C FOR 1 HOUR. MAX. TEMP. REACHED 308°C OVEN SWITCHED OFF AND LEFT TO COOL.
400
350
300
250
200
150
100
50
0
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
TIME (MINS)


A GRAPH TO SHOW TEMP RISE AGAINST
TIME FOR TAPES D E AND F
RESET OVEN
1 HOUR
TAPE E (MYLAR)
1 HOUR TAPE F (MYLAR)
1 HOUR
TAPE D (MYLAR)
TAPE D LEFT TO SOAK AT 100°C FOR
1 HOUR. MAX. TEMP 114°C
TAPE E LEFT TO SOAK AT 140°C FOR
1 HOUR. MAX. TEMP 145°C
TAPE F LEFT TO SOAK AT 120°C FOR
1 HOUR. MAX. TEMP. 120°C
150
125
100
75
50
25
0
5
10
15
20
25
30
35
40
45
50
55
TIME (MINS)
PAGE 8

APPENDIX K

THERMAL ANALYSIS OF PROPOSED SOLID-STATE AIRCRAFT CRASH RECORDER

APPENDIX K

THERMAL ANALYSIS OF PROPOSED SOLID-STATE AIRCRAFT CRASH RECORDER

INTRODUCTION

Normalair-Garrett Limited (NGL) has prepared a design proposal for a solid-state aircraft crash recorder. The design has been optimized to meet various thermal, shock, and impact requirements.

Reasonable assurance was required that component temperatures would not exceed manufacturer's recommended levels for recording data under normal aircraft operating conditions and for maintaining data integrity for removal after an aircraft crash. This appendix describes the thermal analysis undertaken to estimate internal temperature profiles for the crash recorder design proposal (shown in Ref. K-1).

Initial analysis indicated that it was not possible to use an inert insulation alone since the thickness required for crash protection did not permit adequate heat dissipation during normal working. A combination of passive insulation and an external coating of intumescent material provided the best solution. Recent experience with designs for crash protection, which included a survey of the attributes of many insulators, suggested that MIN K 2000 and FIREC would be suitable passive and intumescent insulations, respectively. The analysis described below was based on the thermal properties of these substances.

The analysis was divided into two parts:

(a) Derivation of the temperature levels inside the unit under normal power loading in the worst-case environmental situation.

(b) Transient analysis of the effects of a flame test, which simulates fire in the crash situation.

It was necessary to optimize the amounts of passive and intumescent insulations to meet the requirements for normal operation and crash protection.

THERMAL CONSTRAINTS

The following information was used as a basis for the thermal analyses:

(a) Normal recording

  (1) Solid-state component operating temperatures should not exceed 125°C

  (2) Total power to be dissipated is 3.5 w

  (3) Ambient temperature is 90°C

(b) Crash protection

(1) To ensure successful data retrieval, solid-state component temperatures should not exceed 150°C

(2) In the absence of detailed information that described the performance of the FIREC intumescent coating, experimentally measured temperature profiles were extracted from tests performed at NGL and input to a model of the crash recorder. Ref. K-2 describes the fire test.

(3) Soak at 90°C prior to fire test simulation

THERMAL MODEL

Salient details have been extracted from the design in Ref. K-1 in order to simplify the analysis. It should be noted that assumptions made to ease the mathematical interpretation were calculated to err on the side of safety.

HEAT DISSIPATION

Figure K-1 shows the analogous electrical network adopted for the heat transfer paths from the internal case, which holds the solid-state components, to the ambient. The heat capacities of the protective materials have been included so that a transient analysis may be performed. Table K-1 lists the resistances and capacitances calculated for the network. Superimposed on the margin are indications of the thicknesses of materials used in the analysis.

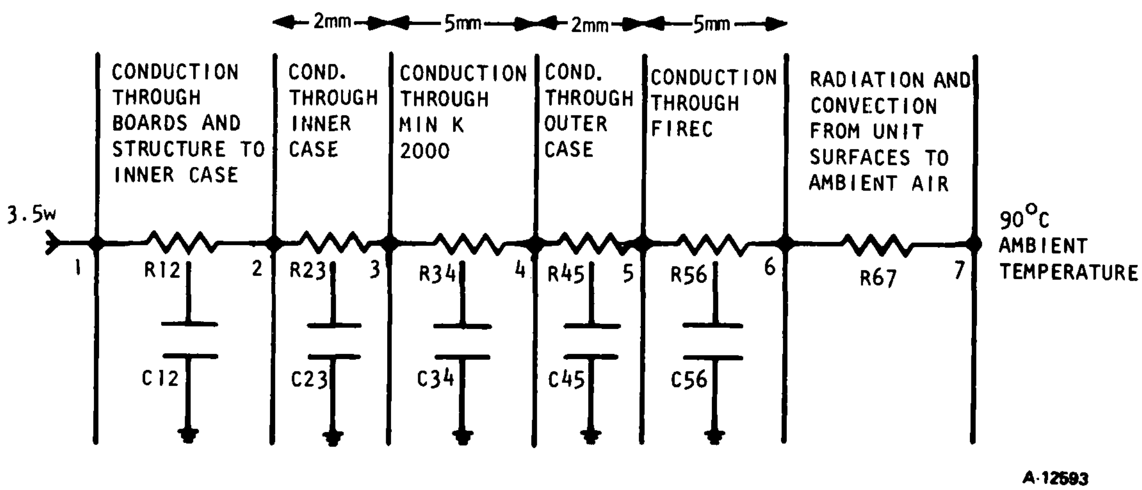


Figure K-1. Network for Heat Dissipation Under Normal Operating Conditions

TABLE K-1

RESISTANCES AND CAPACITANCES FOR THERMAL NETWORK

Component	Resistance	Capacitance
Inner compartment	1.5	510
Inner case (steel)	1.16×10^{-3}	555
MIN K 2000	1.04	106
Outer case (steel)	1.04×10^{-3}	622
FIREC	0.308	100
Air radiation and convection	1.0	--

The network permits the derivation of temperature profiles for a number of points inside the unit:

(a) A fictious point in the center of the unit where all the solid-state components were considered to be

(b) Internal compartment/inner steel case

(c) Inner steel case/MIN K 2000 internal insulation

(d) MIN K 2000/outer steel case

(e) Outer steel case/FIREC intumescent

(f) Skin

(g) Ambient

Table K-2 lists steady-state temperatures calculated at each of the above points in an ambient temperature of 90°C and a power loading of 3.5 w in the internal compartment. There was insufficient time to conclude a transient analysis.

The internal compartment temperature attains a steady-state value of 105°C, which falls below the maximum specified for normal data recording purposes.

CRASH PROTECTION

Figure K-2 shows the network chosen to represent heat transfer in the crash situation. Data from Ref. K-2 for outer steel case temperatures during the fire test (covered by a 4.5-mm coating of FIREC intumescent) was input to the network as an equivalent exponential temperature increase.

TABLE K-2

INTERNAL TEMPERATURES - HEAT DISSIPATION (3.5 W)
UNDER NORMAL OPERATING CONDITIONS

Position of Temperature Estimate	Temperature, °C
Ambient	90.0
Skin (FIREC)	93.5
FIREC/outer case	94.6
Outer case/MIN K 2000	94.6
MIN K 2000/inner case	98.3
Inner case/internal comp.	98.3
Solid-state components	104.5

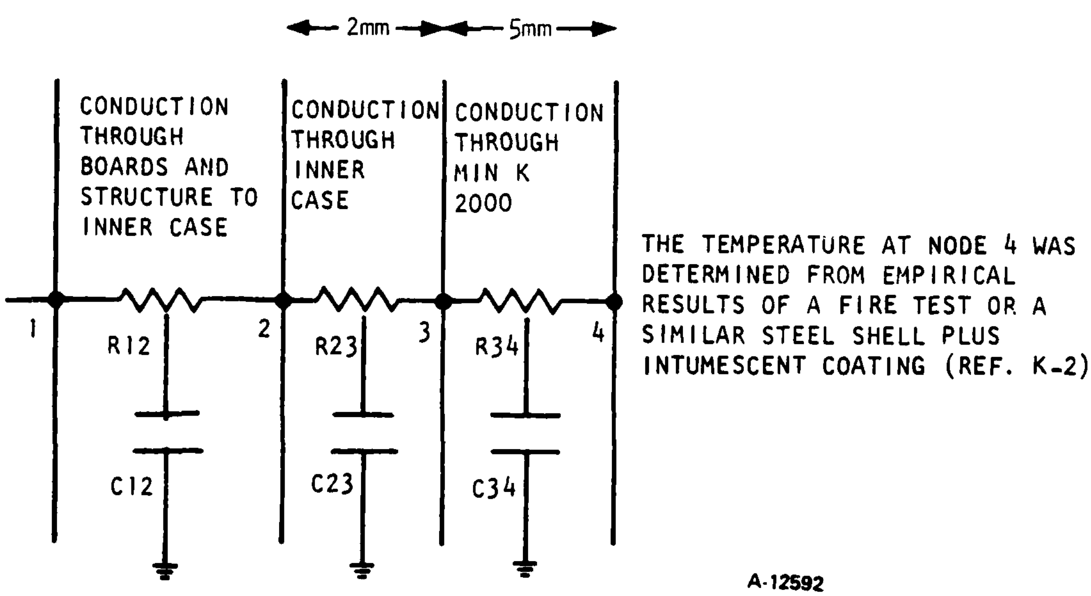


Figure K-2. Network for Crash Protection Thermal Analysis

The network allows the estimation of temperature profiles for the following internal points:

(a) A ficticious point in one center of the unit where all the solid-state components were considered to exist

(b) Internal compartment/inner steel case

(c) Inner steel case/MIN K 2000

(d) MIN K 2000/outer steel case

Figure K-3a shows time instances of the temperature behavior at each of the above points, starting from 90°C throughout and with an exponential rise in outer case temperature to simulate the fire test. Table K-3 lists the temperatures after 10, 20, and 30 min.

The internal compartment temperature reaches 150°C after 22 min and approaches 190°C after 30 min.

CONCLUSIONS

The design proposal permits adequate heat dissipation during normal data recording conditions--a power load of 3.5 w and an external ambient temperature of 90°C.

Crash protection is sound for 22 min before the internal temperature is estimated to reach 150°C.

REFERENCES

K-1. NGL Drawing No. 1444VDES2, Solid-State Crash Recorder, February 1981.

K-2. NGL Report No. 1305 V DVR 12, Fire Protection Test, September 1980.

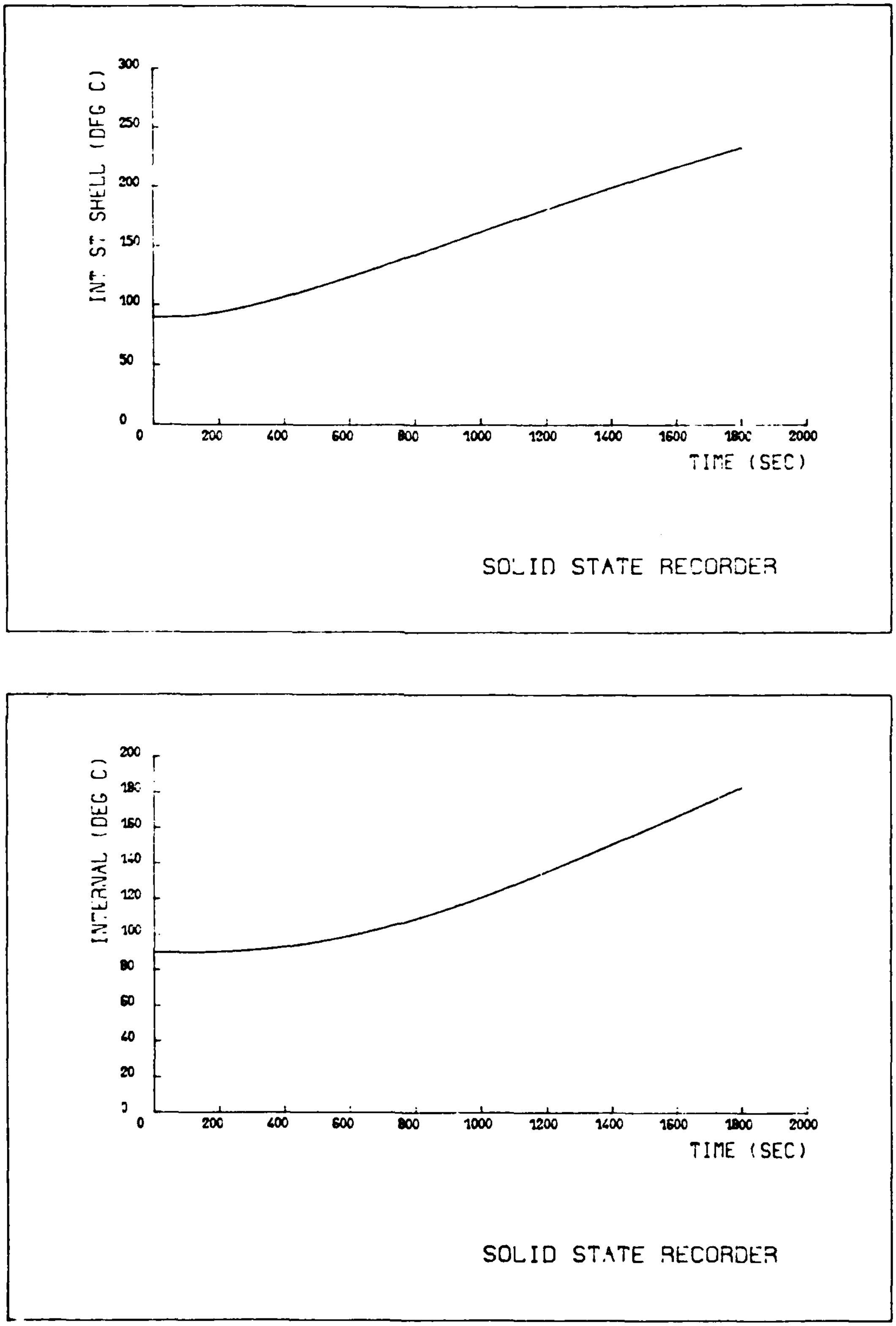
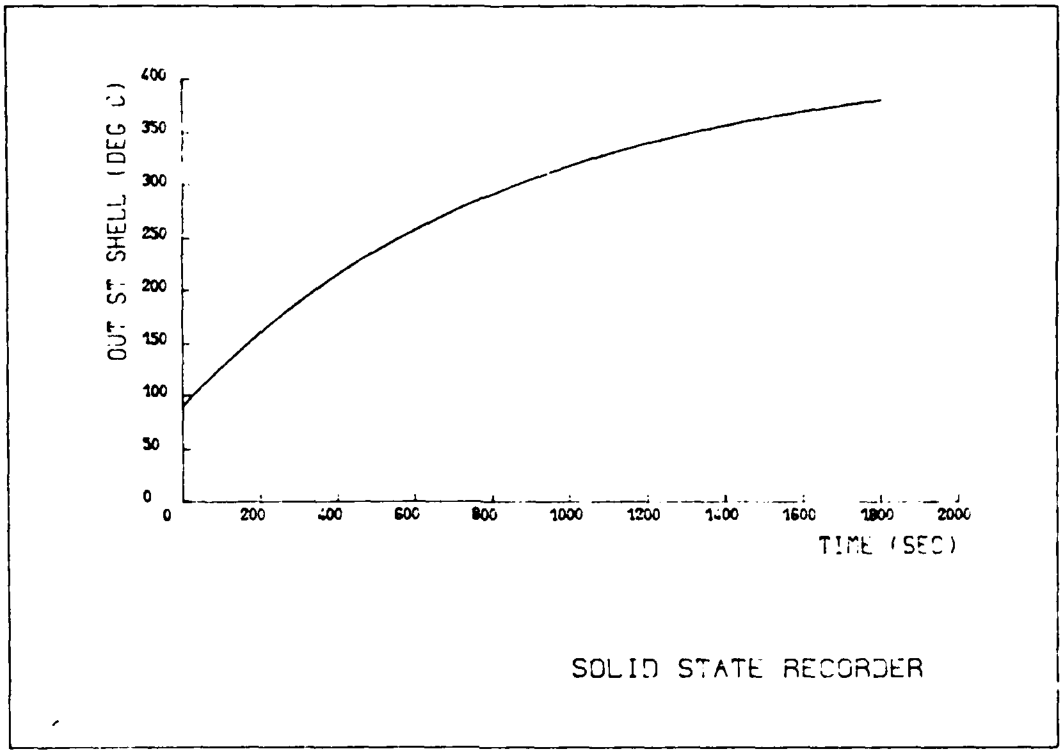


Figure K-3. Results of Thermal Analysis



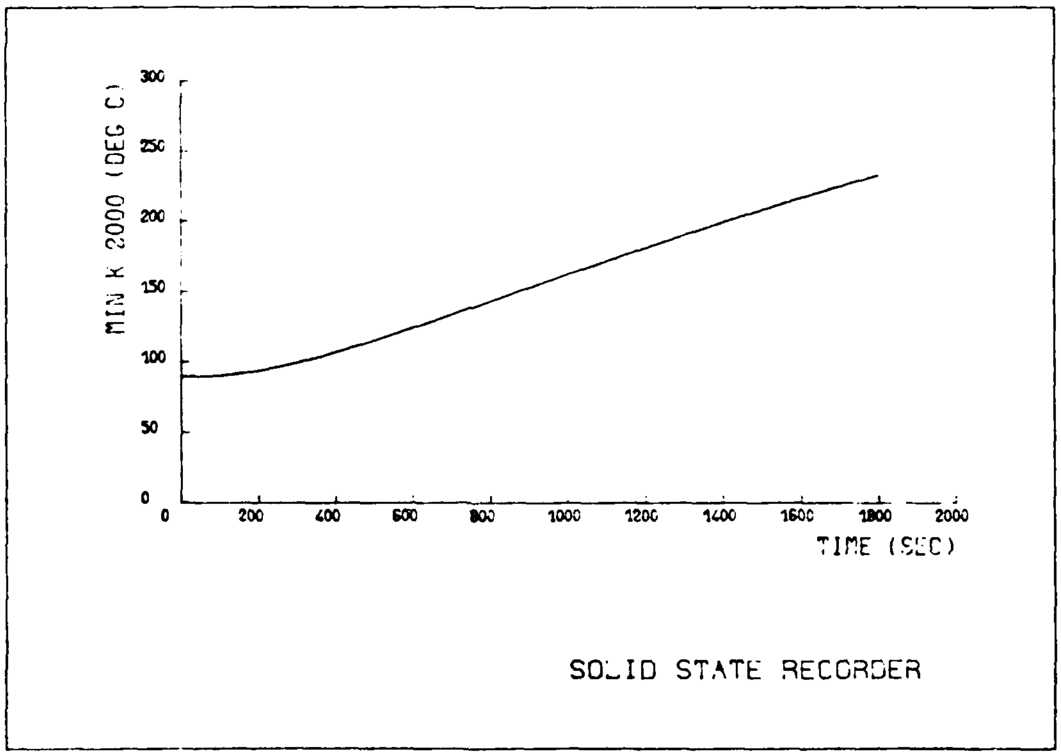


Figure K-3. (Continued)

TABLE K-3

TEMPERATURE ESTIMATES DURING SIMULATED FLAME TEST

Position of Temperature Estimate	Time, min	Temperature, °C
Outer case/MIN K 2000	10	259
	20	341
	[illegible]	381
MIN K 2000/inner case	[illegible]	125
	20	182
	30	233
Inner case/internal com	10	125
	20	182
	30	233
Solid-state components	10	100
	20	136
	30	183

APPENDIX L

LIST OF U.S. PERSONNEL CONTACTED DURING CSFDR STUDY

ADAMS Frank		513 255 6104 Structural Integrity Branch Avionics Flight Dynamics Labs Structural Mech. Div. Structural Integrity Branch Wright Patterson Microprocessor systems to obtain information relating to Fracture mechanics i.e. damage growth (contract award 14th November)
AMMOTT Tom		613 238 4400 Leigh Instruments, Carlton Place Ontario. Product Support
ANDERS Paul	F16 SPO	513 255 4606 Wright Patterson
BATH William		232 3847 Safety Dept. No 295 MCAIR
BRADY Don		516 531 3152 Fairchild Republic A10 Instrumentation
BRILL Lt. John		513 255 5814 Wright Patterson Engine diagnostic system
CAIAFA Ceasar		609 641 8200 Ext. 3320 Federal Aviation Technical Centre Atlantic City, N.J. Carrying out a study into crash conditions for civil and general aircraft. Expects to complete September 1981
CAIGER Bernard		613 998 3149 Flight Research Labs. NAE National Research Council Ottawa, Ontario KI AOR 6 Flight data recorder replay

CAPUTO Captain	THEMS	512 925 6001 Kelly AFB San Antonia Engine Health Monitoring Systems Back 12th November
DICKMAN Thomas		513 255 5357 Wright Patterson AFB Instrumentation A10
DORNEY Chuck	F15 SPO	513 255 3321 Wright Patterson AFB
FAGEN Scott		213 386 5557 International Society of Air Safety Box 20742 LA 90006
FINGER John		804 827 1110 Ext. 3681 Mail Stop 477 NASA, Langly Research Centre Hampton, Virginia 23665 Study into methods of obtaining statistical data for aircraft structural strength requirements
GEMIN Bob	GSFDR Engineer	513 255 3440 Wright Patterson AFB
HAUPT Lt. Stephen	F16 SPO	513 255 4606 Wright Patterson AFB
HAYES Jack	Recorder Deptt	301 344 7779 NASA Goddard
HOUSE Tom		804 878 3507 AVRADCOM Ft. Eustace Black Hawk Maintenance Recorder
JAYORE Dr.	Data Compression	205 453 5607 MFSC Needs programme
KNIGHT Venny		see John Finger Responsible for recorders at Langley Research Centre

KUBIAC Captain Jim		513 255 5814
		Wright Patterson Engine diagnostic system
LERAAS Melvin	F16 Instrumentation	513 255 3440
		Wright Patterson AFB
LYNCH Dr. Tom	Data Compression	801 344 6445 (Goddard)
MAXWELL Marvin		301 344 8036
		NASA (Goddard)
		Data compression of Video signals
MAYNARD Karl	Data Compression	205 453 3171
		Marshall Flight Space Centre-p
McLEACH Walt		613 992 2451
		Dept. of Transport, Ottawa Airline Regulatory Authority
MILLER Warner	Data Compression	301 344 8183 (Goddard)
NORMAN Dave		Wright Patterson AFB
		Flight Regime/Aerodynamics for A10
PARKER John		~~5225~~ 415 965 5225
		NASA AIMS Research Centre intensity of aircraft fires
PECKHAM Cyril	ASIP	513 255 4988
		Wright Patterson AFB
RICE Bob	Data Compression	213 354 2616
		JPL NASA Pasadena Ca.
SILER Bern		205 453 4340
		Marshall Flight Space Centre EF 13, MFSC, Alabama 35812
		Evaluation of recorders
SOUKUP Bill	F15 Instrumentation	513 255 3913
		Wright Patterson AFB

WALLACE Charlie	F15 Maintenance	912 926 2901
		Warner Robbins AFB
WALLACE Dr. Gabriel		2c5 453 3777
		Marshall Flight Space Centre
		Branch chief for Bern Siler
WILLIAMS Dell	Data Compression	2o2 755 2370
		OAST Space Systems
WOOD A.D.		613 998 3071
		NRC Ottawa Flight Research Labs. Uplands
ZENOVIC Ron		213 354 3444
		JPL

STUKENBORG Douglas	513 255 5814 Wright Patterson AFB Engine diagnostic system
TAYLOR Frank - Flight Safety Director	202 472 6066 NTSB
THOMAS Doug	205 453 3577 Marshall FSC Data compression on NEEDS programme spectral imagery, non information data compression
THOMSON Dr. R.G.	804 827 1110 Ext. 3795 Langley Impact dynamics research facility provided details of shock to be expected in crash
THOR Wayne	Wright Patterson AFB Stability Augmentation system A10
TYNDALE Robert	Wright Patterson AFB Flight Regime/Aerodynamics for A10
VELDMAN Ray ASIP	Wright Patterson AFB 513 255 4988

Dr. Carol Roberts	NTSB	(202) 472-6131
Paul Turner	NTSB	
Dan Watters	Naval Systems Engineering Test Directorate, NATC	(301) 863-4673
Bill Red	Naval Air Station, North Island	(714) 437-5631
Ray Rank	NAVAIR	(202) 692-0751
Jim Vreeland	Navy Safety Control, Norfolk	(804) 444-1521
Lt. John Brill	Wright Patterson Engine Performance Monitoring	(513) 255-3279
Dave Godfried	Leigh Instruments, North Island	(714) 437-5631
Ken Fields	Director, Navair Safety Office	(202) 692-1236
Bill Currie	Wright Patterson Engine Health Monitoring	(513) 255-3279

APPENDIX M

ANALYSIS OF USAF AIRCRAFT CRASHES

Electronics
(Aerospace)
Division

TECHNICAL REPORT NO. NY.1245 Copy No. 7.

U.S.A.F. NORTON INCIDENT
REPORTS - STATISTICAL ANALYSIS

Submitted by

C. Paynter

C.Paynter - Jnr. Systems Analyst

Approved by

A.C.Rolfe - Manager - System Studies

DECEMBER 1980

AIRESEARCH MANUFACTURING COMPANY

SUMMARY

This report presents the analysis performed on incident reports from Norton USAF training base. The reports were categorised and numerically coded to allow computerised analysis.

It was found that in over half of the incidents resulting in loss of aircraft the findings of the crash committee were inconclusive representing a significant loss of aircraft and personnel.

It has been shown that of the incidents that had conclusive findings a high proportion were due to failure in areas, such as the engine, which lend themselves to data collection. This suggests that in a large proportion of the incidents involving aircraft and personnel loss, a data recorder would have produced a positive effect on the incident findings.

CONTENTS

1. INTRODUCTION

This report concerns a survey of aircraft incidents and crashes, undertaken to assist in the identification of areas and causes of failure on military aircraft.

The incident reports summarise the findings of crash committees at the Norton U.S.A.F. base over the period from 1976 to date and cover over 800 incidents.

The reports have been broken down into categories which allow an incident to be classified uniquely and facilitates a numerical description of the findings. The categorised summaries are then used as input data for computerised statistical analysis.

A detailed description of the main and sub categories is given in Section 2 with the results of the statistical analysis in Section 3.

2. REPORT CATEGORIES

The first 30 reports were reviewed to give an indication of the categories necessary to correctly describe an incident. The main categories describe:-

a) Incident Classification
b) Cause of Incident
c) Area(s) of failure(s) on the aircraft
d) Results of the failure(s)

The following sections describe the sub categories of the above, which were then coded for use by the computer programs.

2.1 Classification

The following categories classify an incident uniquely:-

Category	Type of Entry
Incident Number	9 figure integer
Aircraft Type	5 figure alphanumeric
Accident Class	0 or 1
Injury Class	0 or 1
Phase of Operation	0, 1, 2 or 3
Page Number	3 figure integer

There are 4 alternatives in the phase of operation category:-

0 = Parked
1 = Take off
2 = Cruise
3 = Landing

Taxiing is considered to be mode 1 or 3 depending on prior circumstances. In the accident class category, a 1 or 0 corresponds to U.S.A.F. Class A or B accidents. Class A accidents imply serious damage or loss of aircraft whereas Class B accidents suggest repairable damage. Injury Class 1 corresponds to serious injuries whilst Class 0 refers to slight or no injuries.

2.2 Cause of Incident

It should be noted that, in this and following sections, the categories are not unique, i.e. more than one cause can occur in one incident.

The following categories are used to code the cause of failure:

Category	Type of Entry
Pilot Error	0, 1 or 2
Control Equipment Failure	0 or 1
Environmental Factors	0 or 1
Material Failures	0 or 1
Other known Causes	0 or 1
Unknown Causes	0 or 1

0 or 1 corresponds to NO or YES

Description

a) Pilot Error : There are 3 alternatives 0, 1 or 2 which corresponds to no pilot error, confirmed pilot error and the failure was assigned to pilot error but the report findings were inconclusive.

b) Control Equipment Failure : Yes or No; This category includes instrumentation malfunction (e.g. failure of radar)

c) Environmental Factors : Yes or No; This is mainly Bird Damage but includes ice damage and other effects of the weather (e.g.lightning)

d) Material Failure : Yes or No; Failure due to overstressed members, fatigue and corrosion. Also includes failure of part due to unsatisfactory maintenance.

e) Other known Causes : Yes or No; This category consists in the main, of foreign object damage (F.O.D.) to the aircraft, especially the engine.

f) Unknown Cause : Yes or No; This category is used when the report committee could not ascertain the cause of an incident.

2.3 Areas of Aircraft

The categories in this section present the area(s) of the aircraft where the failure(s) occurred.

Category	Type of Entry
Engine	0 or 1
Landing Gear	0 or 1
Cockpit	0 or 1
Control Surfaces	0 or 1
Other Areas	0 or 1

Some of these categories can be easily interpreted and only require YES or NO (1 or 0) answers but the categories below require more explanation.

a) Cockpit : Yes or No; When a pilot error occurs the area of failure is assigned to be the cockpit. The cockpit also includes instrumentation failure.

b) Control Surfaces : Yes or No; This area includes wing tips, ailerons, flaps, rudders, etc.

c) Other Areas : Yes or No; This area consists of fuselage and attached missiles.

2.4 Result of Failure

Category	Type of Entry
Ejection	0 or 1
Onboard Fire	0 or 1
No. of Aircraft Lost	Integer
No. of Personnel Lost	Integer

a) Fire : Yes or No; This category does not include impact with ground, water or buildings.

b) No. of Personnel Lost : INTEGER; Personnel lost implies fatality or a major injury which would result in permanent injury and/or grounding.

3. PRESENTATION OF RESULTS

Table 1 presents the initial calculations performed on the data and shows the variation of the categories with phase of operation. The right hand column of Table 1 shows the percentage of all incidents for each category. These figures are shown in Figure 1 as bar charts. Referring to Figure 1 the following statements can be made.

a) 38% of incidents resulted in loss of aircraft

b) 22% of incidents resulted in loss of personnel

Table 1 shows the number of personnel lost is 262, which is significantly higher than the number of incidents when personnel were lost, resulting in the probability of loss of life in an incident being 0.32.

In Figure 1(b) the section of the chart labelled "inconclusive findings" is the combination of Pilot Error (2), Control Equipment Failure and Unknown cause. This represents the percentage of cases, when the findings of the crash committee were considered inconclusive, and, when a data recorder would have produced a positive effect on the report findings.

c) 32% of all incident reports were inconclusive

In Figure 1(b) "other causes" is the dominant single category. This mainly consists of foreign object damage which results in minor, repairable damage to the aircraft, particularly the engine. This is shown in Figure 1(c) where the engine area dominates the other categories.

It is of particular interest to look at the results when the plane is in operation, i.e. when it is not in the parked mode. Figure 2 analyses the results of Table 1 when the cases in which the aircraft is parked are not considered. This reduces the population size to 677 from 818 and has the effect of reducing the domination of the engine, as shown in Figure 2(c), and increases the proportion of incident reports with inconclusive findings. These results occur because of the high number of engine foreign object damage incidents discovered during a pre-flight and post-flight inspections.

Statements a), b) and c) now become, respectively:

d) 46% of incidents (excluding parked) resulted in loss of aircraft

e) 26% of incidents (excluding parked) resulted in loss of personnel

f) 35% of incident reports (excluding parked) were inconclusive.

The results of analysis when only Class A accidents are considered are presented in Tables 2 and 3 and shown as bar charts in Figures 3 and 4.

The section labelled " inconclusive findings" in Figure 3 is as previously described and shows that 53% of the total number of aircraft lost gave rise to crash reports with inconclusive findings.

In Figure 4 the cockpit area, containing all the pilot error incidents, is the most significant category containing 58% of all class A accidents. It must be noted that the crash reports arise from a training base, so may present a higher proportion of pilot error incidents than would normally be expected.

On further analysis of Class A cases it was found that 6.2% of all aircraft lost crashed in the sea.

A number of miscellaneous cross-references were performed from which the significant results are

a) 11.6% of all incidents were due to material failure in the engine

b) 4.3% of all incidents were due to material failures in the landing gear

4. CONCLUSIONS

In over half of the cases involving loss of aircraft there was insufficient evidence to support the formulation of a conclusive finding. Included in this category are the following types of accidents:-

a) accidents attributed in part to pilot error but where the reason for the pilots inability to control the aircraft was not clear.

b) control systems failure where although the area was identified the cause was unknown.

c) accidents which occurred for a completely unknown reason.

These groups form the sample of Class A accidents most likely to have benefited from the recording of aircraft conditions. It is not possible, from these statistics, to state definitely that the presence of a data recorder would have prevented further accidents, but of the reports with conclusive findings a high proportion of failures occurred in areas which lend themselves to data collection. This suggests that in a large number of the inconclusive accidents, involving aircraft and personnel loss, a data recorder would have produced a positive effect on the report findings.

PHASE	PARKED	TAKE-OFF	CRUISE	LANDING	TOTAL	% OF ALL INCIDENTS
No.of cases when aircraft lost	2	24	233	52	312	38.1
No.of cases when personnel lost	1	5	151	20	177	21.6
Ejection	0	13	155	24	192	23.4
Onboard Fire	8	24	40	11	83	10.1
Pilot Error (1)	1	8	103	49	161	19.7
Pilot Error (2)	0	1	69	8	78	9.5
Control Equipment Failure	3	12	55	25	95	11.6
Environ-mental Factors	2	9	47	18	76	9.2
Material Failure	9	26	102	33	170	20.7
Other Causes (F.O.D)	111	29	105	16	261	31.9
Unknown Causes	18	13	81	13	125	15.2
Engine Area	138	56	164	34	392	47.9
Landing Gear Area	0	12	12	43	67	8.2
Cockpit Area	0	10	173	51	234	28.6
Control Surfaces	5	2	27	5	39	4.7
Other Areas	3	13	91	13	120	14.7
No. of Aircraft Lost	3	24	245	53	325	N/A
No. of Personnel Lost	1	8	223	30	262	N/A

TABLE 1

VARIATIONS WITH PHASE OF OPERATION

Cause of Failure	No.of Aircraft Lost	% of total number of lost aircraft	% of all incidents
Pilot Error (1)	100	30.7	12.2
Pilot Error (2)	70	21.5	8.5
Control Equipment Failure	58	17.8	7.1
Environmental Factors	18	5.5	2.2
Material Failures	55	16.9	6.7
Other Known Causes	39	12.0	4.7
Unknown Causes	70	21.5	8.5

TABLE 2

Areas of Aircraft	No. of Cases	% of all Class A Cases	% of all Incidents
Engine	74	23.7	9.0
Landing Gear	19	6.1	2.3
Cockpit	180	57.7	22.0
Control Surfaces	21	6.7	2.5
Other Areas	39	12.5	4.7

TABLE 3

TABLES 2 and 3 : VARIATIONS WITH CLASS A ACCIDENTS

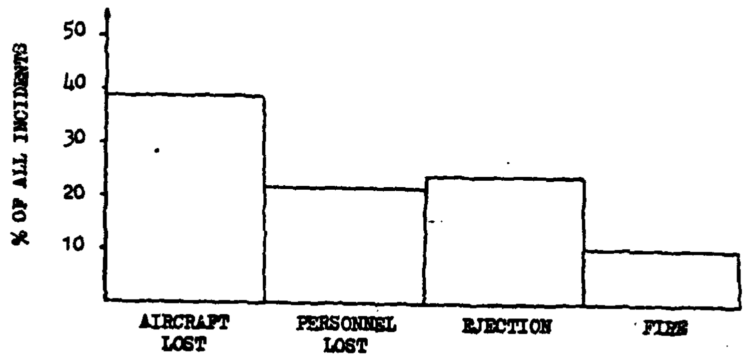


FIGURE 1(a)

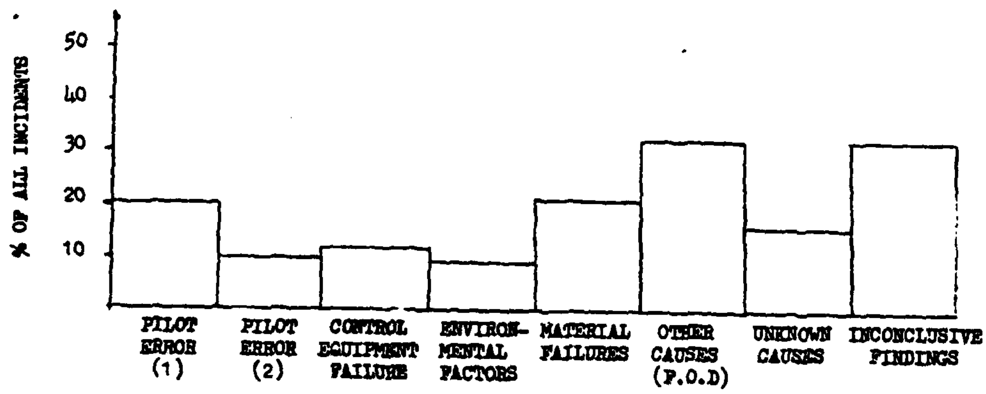


FIGURE 1(b)

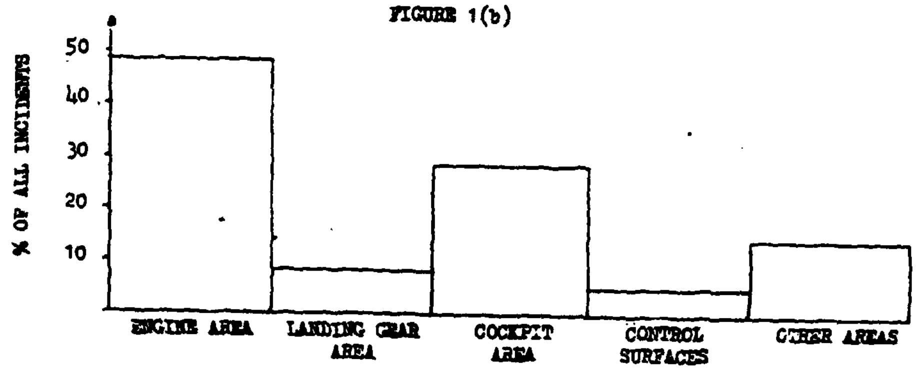


FIGURE 1(c)

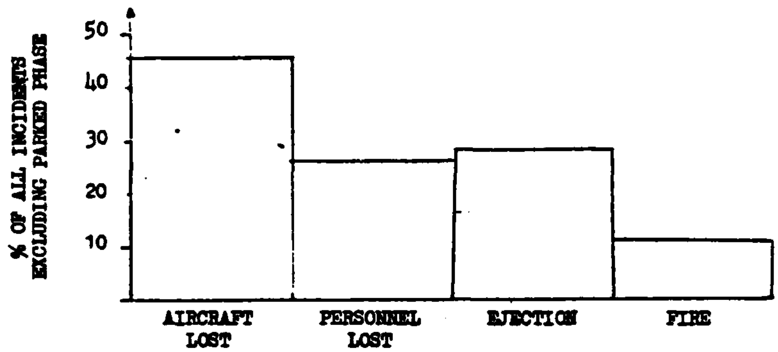


FIGURE 2(a)

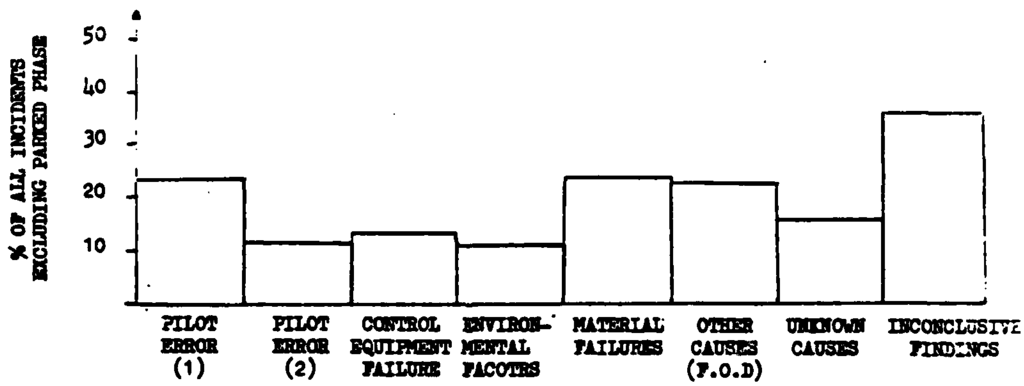


FIGURE 2(b)

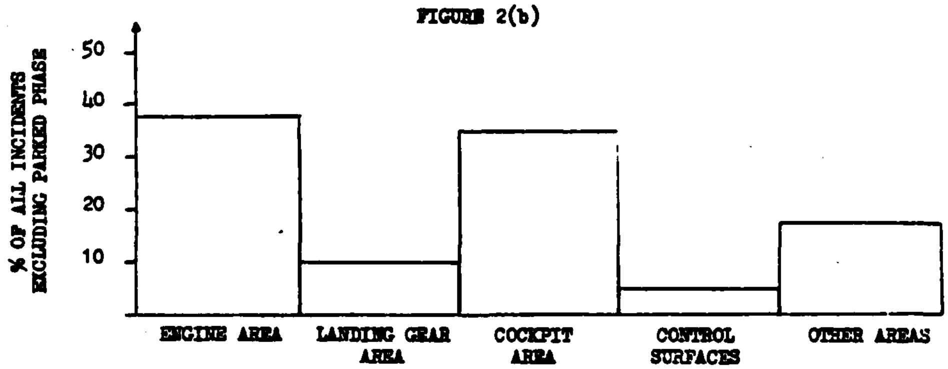


FIGURE 2(c)

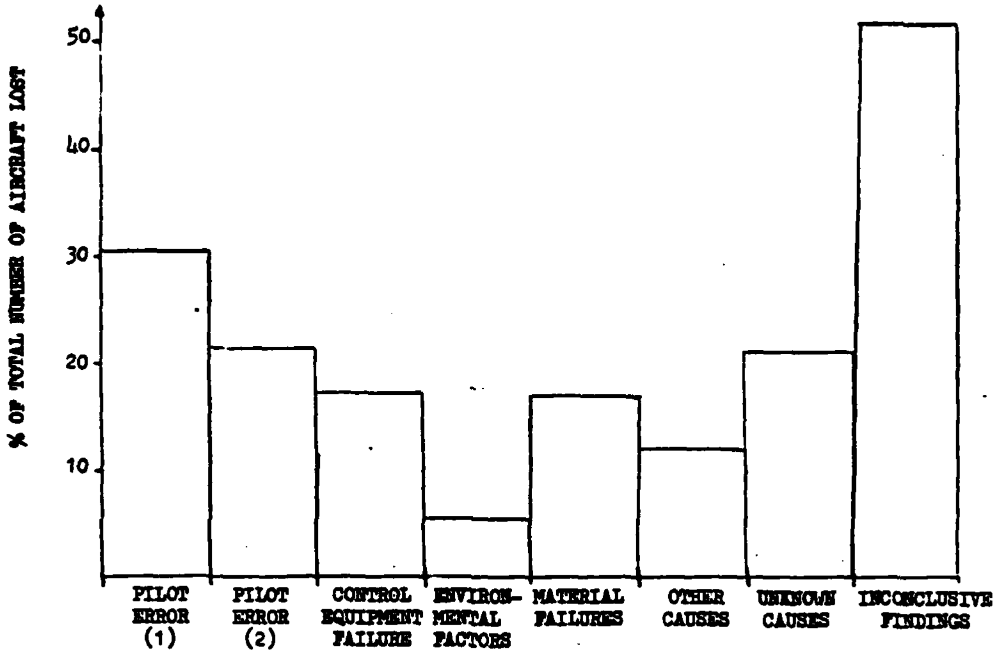


FIGURE 3

CAUSES OF FAILURE FOR CLASS A ACCIDENTS

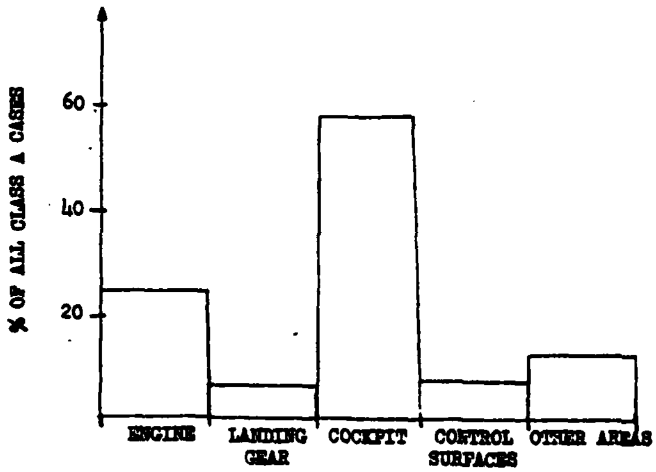


FIGURE 4

AREAS OF FAILURE FOR CLASS A ACCIDENTS

APPENDIX

VARIATION OF CATEGORIES

WITH AIRCRAFT TYPE

AIRCRAFT TYPE F004

	CASES	PERCENT
PARKED	85	26.154
TAKE OFF	35	10.769
CRUISE	164	50.462
LANDING	99	30.462
PILOT1	52	16.000
PILOT 2	99	30.462
CON.EQUIP	31	9.538
ENVIRONMENT	22	6.769
MATERIAL	65	20.000
OTHER	126	38.769
UNKNOWN	38	11.692
ENGINE	179	55.077
LANDING GR	26	8.000
COCKPT	77	23.692
CONT.SUR	10	3.077
OTHER	47	14.462
EJECTION	54	16.615
FIRE	30	9.231
ACR.LOST	87	26.769
LIVES LOST	56	26.769
NO. ACR.LOST	93	
NO. LIVES LOST	103	

TOTAL NUMBER OF THIS TYPE- 325

AIRCRAFT TYPE F015

	CASES	PERCENT
PARKED	16	17.582
TAKE OFF	8	8.791
CRUISE	53	58.242
LANDING	24	26.374
PILOT1	11	12.088
PILOT 2	24	26.374
CON.EQUIP	11	12.088
ENVIRONMENT	11	12.088
MATERIAL	12	13.187
OTHER	38	41.758
UNKNOWN	19	20.879
ENGINE	49	53.846
LANDING GR	5	5.495
COCKPT	20	21.978
CONT.SUR	5	5.495
OTHER	15	16.484
EJECTION	13	14.286
FIRE	7	7.692
ACR.LOST	24	26.374
LIVES LOST	6	26.374
NO. ACR.LOST	25	
NO. LIVES LOST	9	

TOTAL NUMBER OF THIS TYPE- 91

AIRCRAFT TYPE F111

	CASES	PERCENT
PARKED	18	23.077
TAKE OFF	6	7.692
CRUISE	41	52.564
LANDING	35	44.872
PILOT1	11	14.103
PILOT 2	35	44.872
CON.EQUIP	8	10.256
ENVIRONMENT	11	14.103
MATERIAL	17	21.795
OTHER	25	32.051
UNKNOWN	11	14.103
ENGINE	41	52.564
LANDING GR	7	8.974
COCKPT	22	28.205
CONT.SUR	4	5.128
OTHER	8	10.256
EJECTION	17	21.795
FIRE	13	16.667
ACR.LOST	31	39.744
LIVES LOST	20	39.744
NO. ACR.LOST	33	
NO. LIVES LOST	37	

TOTAL NUMBER OF THIS TYPE- 78

AIRCRAFT TYPE T038

	CASES	PERCENT
PARKED	2	2.740
TAKE OFF	14	19.178
CRUISE	33	45.205
LANDING	32	43.836
PILOT1	23	31.507
PILOT 2	32	43.836
CON.EQUIP	12	16.438
ENVIRONMENT	13	17.808
MATERIAL	15	20.548
OTHER	10	13.699
UNKNOWN	7	9.589
ENGINE	29	39.726
LANDING GR	8	10.959
COCKPT	25	34.247
CONT.SUR	6	8.219
OTHER	4	5.479
EJECTION	18	24.658
FIRE	3	4.110
ACR.LOST	25	34.247
LIVES LOST	19	34.247
NO. ACR.LOST	26	
NO. LIVES LOST	27	

TOTAL NUMBER OF THIS TYPE- 73

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AIRCRAFT TYPE A007

	CASES	PERCENT
PARKED	3	6.818
TAKE OFF	4	9.091
CRUISE	33	75.000
LANDING	24	54.545
PILOT1	11	25.000
PILOT 2	24	54.545
CON.EQUIP	6	13.636
ENVIRONMENT	1	2.273
MATERIAL	9	20.455
OTHER	11	25.000
UNKNOWN	5	11.364
ENGINE	18	40.909
LANDING GR	3	6.818
COCKPT	23	52.273
CONT.SUR	0	.000
OTHER	4	9.091
EJECTION	22	50.000
FIRE	1	2.273
ACR.LOST	32	72.727
LIVES LOST	20	72.727
NO. ACR.LOST	33	
NO. LIVES LOST	23	

TOTAL NUMBER OF THIS TYPE= 44

AIRCRAFT TYPE A010

	CASES	PERCENT
PARKED	5	12.500
TAKE OFF	0	.000
CRUISE	30	75.000
LANDING	13	32.500
PILOT1	9	22.500
PILOT 2	13	32.500
CON.EQUIP	7	17.500
ENVIRONMENT	6	15.000
MATERIAL	8	20.000
OTHER	13	32.500
UNKNOWN	6	15.000
ENGINE	17	42.500
LANDING GR	0	.000
COCKPT	12	30.000
CONT.SUR	2	5.000
OTHER	10	25.000
EJECTION	10	25.000
FIRE	6	15.000
ACR.LOST	17	42.500
LIVES LOST	11	42.500
NO. ACR.LOST	17	
NO. LIVES LOST	11	

TOTAL NUMBER OF THIS TYPE= 40

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AIRCRAFT TYPE F106

	CASES	PERCENT
PARKED	2	5.128
TAKE OFF	5	12.821
CRUISE	24	61.538
LANDING	16	41.026
PILOT1	10	25.641
PILOT 2	16	41.026
CON.EQUIP	5	12.821
ENVIRONMENT	5	12.821
MATERIAL	12	30.769
OTHER	10	25.641
UNKNOWN	9	23.077
ENGINE	10	25.641
LANDING GR	8	20.513
COCKPT	13	33.333
CONT.SUR	1	2.564
OTHER	9	23.077
EJECTION	8	20.513
FIRE	5	12.821
ACR.LOST	15	38.462
LIVES LOST	7	38.462
NO. ACR.LOST	15	
NO. LIVES LOST	8	

TOTAL NUMBER OF THIS TYPE- 39

AIRCRAFT TYPE F105

	CASES	PERCENT
PARKED	2	5.556
TAKE OFF	4	11.111
CRUISE	22	61.111
LANDING	10	27.778
PILOT1	5	13.889
PILOT 2	10	27.778
CON.EQUIP	8	22.222
ENVIRONMENT	1	2.778
MATERIAL	10	27.778
OTHER	6	16.667
UNKNOWN	14	38.889
ENGINE	14	38.889
LANDING GR	4	11.111
COCKPT	8	22.222
CONT.SUR	4	11.111
OTHER	8	22.222
EJECTION	19	52.778
FIRE	8	22.222
ACR.LOST	26	72.222
LIVES LOST	10	72.222
NO. ACR.LOST	26	
NO. LIVES LOST	11	

TOTAL NUMBER OF THIS TYPE- 36

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AIRCRAFT TYPE F100

	CASES	PERCENT
PARKED	2	9.091
TAKE OFF	1	4.545
CRUISE	15	68.182
LANDING	8	36.364
PILOT1	11	50.000
PILOT 2	8	36.364
CON.EQUIP	0	.000
ENVIRONMENT	4	18.182
MATERIAL	6	27.273
OTHER	5	22.727
UNKNOWN	2	9.091
ENGINE	9	40.909
LANDING GR	2	9.091
COCKPT	8	36.364
CONT.SUR	2	9.091
OTHER	3	13.636
EJECTION	10	45.455
FIRE	2	9.091
ACR.LOST	14	63.636
LIVES LOST	8	63.636
NO. ACR.LOST	15	
NO. LIVES LOST	9	

TOTAL NUMBER OF THIS TYPE= 22

AIRCRAFT TYPE F005

	CASES	PERCENT
PARKED	0	.000
TAKE OFF	4	23.529
CRUISE	11	64.706
LANDING	6	47.059
PILOT1	5	29.412
PILOT 2	8	47.059
CON.EQUIP	0	.000
ENVIRONMENT	0	.000
MATERIAL	5	29.412
OTHER	6	35.294
UNKNOWN	2	11.765
ENGINE	5	29.412
LANDING GR	1	5.882
COCKPT	8	47.059
CONT.SUR	0	.000
OTHER	3	17.647
EJECTION	3	17.647
FIRE	2	11.765
ACR.LOST	9	52.941
LIVES LOST	5	52.941
NO. ACR.LOST	10	
NO. LIVES LOST	6	

TOTAL NUMBER OF THIS TYPE= 17

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AIRCRAFT TYPE 1057

	CASES	PERCENT
PARKED	0	.000
TAKE OFF	3	21.429
CRUISE	5	35.714
LANDING	8	57.143
PILOT1	8	57.143
PILOT 2	8	57.143
CON.EQUIP	0	.000
ENVIRONMENT	1	7.143
MATERIAL	3	21.429
OTHER	3	21.429
UNKNOWN	2	14.286
ENGINE	4	28.571
LANDING GR	0	.000
COCKPT	8	57.143
CONT.SUR	0	.000
OTHER	2	14.286
EJECTION	4	28.571
FIRE	3	21.429
ACR.LOST	8	57.143
LIVES LOST	2	57.143
NO. ACR.LOST	8	
NO. LIVES LOST	2	
TOTAL NUMBER OF THIS TYPE-		14

AIRCRAFT TYPE F101

	CASES	PERCENT
PARKED	3	25.000
TAKE OFF	3	25.000
CRUISE	3	25.000
LANDING	9	75.000
PILOT1	1	8.333
PILOT 2	9	75.000
CON.EQUIP	4	33.333
ENVIRONMENT	0	.000
MATERIAL	3	25.000
OTHER	2	16.667
UNKNOWN	1	8.333
ENGINE	2	16.667
LANDING GR	2	16.667
COCKPT	5	41.667
CONT.SUR	0	.000
OTHER	3	25.000
EJECTION	2	16.667
FIRE	1	8.333
ACR.LOST	5	41.667
LIVES LOST	5	41.667
NO. ACR.LOST	5	
NO. LIVES LOST	8	
TOTAL NUMBER OF THIS TYPE-		12

AIRCRAFT TYPE F016

	CASES	PERCENT
PARKED	0	.000
TAKE OFF	1	12.500
CRUISE	5	62.500
LANDING	4	50.000
PILOT1	1	12.500
PILOT 2	4	50.000
CON.EQUIP	2	25.000
ENVIRONMENT	0	.000
MATERIAL	2	25.000
OTHER	1	12.500
UNKNOWN	3	37.500
ENGINE	6	75.000
LANDING GR	1	12.500
COCKPT	1	12.500
CONT.SUR	1	12.500
OTHER	1	12.500
EJECTION	4	50.000
FIRE	1	12.500
ACR.LOST	5	62.500
LIVES LOST	0	62.500
NO. ACR.LOST	5	
NO. LIVES LOST	0	

TOTAL NUMBER OF THIS TYPE- 6

AIRCRAFT TYPE F104

	CASES	PERCENT
PARKED	1	12.500
TAKE OFF	0	.000
CRUISE	6	75.000
LANDING	1	12.500
PILOT1	0	.000
PILOT 2	1	12.500
CON.EQUIP	1	12.500
ENVIRONMENT	1	12.500
MATERIAL	1	12.500
OTHER	2	25.000
UNKNOWN	2	25.000
ENGINE	5	62.500
LANDING GR	0	.000
COCKPT	0	.000
CONT.SUR	2	25.000
OTHER	1	12.500
EJECTION	6	75.000
FIRE	0	.000
ACR.LOST	7	87.500
LIVES LOST	1	87.500
NO. ACR.LOST	7	
NO. LIVES LOST	1	

TOTAL NUMBER OF THIS TYPE- 6

AIRCRAFT TYPE A037

	CASES	PERCENT
PARKED	0	.000
TAKE OFF	0	.000
CRUISE	5	100.000
LANDING	0	.000
PILOT1	3	60.000
PILOT 2	0	.000
CON.EQUIP.	0	.000
ENVIRONMENT	0	.000
MATERIAL	0	.000
OTHER	2	40.000
UNKNOWN	1	20.000
ENGINE	2	40.000
LANDING GR	0	.000
COCKPT	3	60.000
CONT.SUR	0	.000
OTHER	0	.000
EJECTION	1	20.000
FIRE	0	.000
ACR.LOST	3	60.000
LIVES LOST	3	60.000
NO. ACR.LOST	3	
NO. LIVES LOST	5	

TOTAL NUMBER OF THIS TYPE- 5

AIRCRAFT TYPE F102

	CASES	PERCENT
PARKED	0	.000
TAKE OFF	0	.000
CRUISE	1	50.000
LANDING	1	50.000
PILOT1	0	.000
PILOT 2	1	50.000
CON.EQUIP	0	.000
ENVIRONMENT	0	.000
MATERIAL	1	50.000
OTHER	0	.000
UNKNOWN	1	50.000
ENGINE	0	.000
LANDING GR	0	.000
COCKPT	1	50.000
CONT.SUR	1	50.000
OTHER	1	50.000
EJECTION	1	50.000
FIRE	1	50.000
ACR.LOST	2	100.000
LIVES LOST	0	100.000
NO. ACR.LOST	2	
NO. LIVES LOST	0	

TOTAL NUMBER OF THIS TYPE- 2