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THE MODULARITY OF THE HEALTH AND USAGE MONITORING SYSTEM

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Abstract

The Health and Usage Monitoring System has functional flexibility or modularity by application, whilst the core of the system, the Health and Usage Monitor, is modular by design and function. It is possible by these means to produce a system which is sufficiently versatile to meet the needs of the rotorcraft operator, the requirements of the rotorcraft and engine manufacturers, and those of the certifying authorities. The purpose of this paper is to outline the range of facilities and functions available at this time for health and usage monitoring.

Data can be accepted by the system from any type of sensor. These data are validated before compression and storage, for subsequent examination, or for immediate utilisation in a variety of functions. The functions themselves can cover the power plant, airframe, transmission and rotor. Experience in the development and application of the system has been gained to a greater or lesser extent in a variety of fixed and rotary winged aircraft, in both civil and military applications; it is this which is the basis of the paper.

1. INTRODUCTION

The purpose of the Health and Usage Monitoring System is to enable the aircraft operator to provide a safe and reliable means of transportation within defined operational limits. This is the objective of all modes of transport and has been for many years.

There was an occasion in the UK, in the middle of the last century, when it was questionable whether a railway engineer and the superintendent should be prosecuted for manslaughter. This was after the failure of a railway axle by fatigue. It precipitated an accident and resulted in the deaths of several passengers. Railway axles and their failure, by what we now know as fatigue, was the topic for discussion at a subsequent meeting of the then recently formed Institution of Mechanical Engineers. The meeting was chaired by Robert Stevenson, designer of the 'Rocket' locomotive, President of the Institution. The railway superintendent of the railway said at the time, 'so certain and regular is the fracture ... from this cause, that we can almost predict in some classes of engines the number of miles that can be run before signs of fracture are visible;'. The superintendent was fortunate in that some of the operational limits were rigidly defined, although the failure themselves were attributed partially to one limiting mechanism, the rail. The chairman warned his fellow members to be on their guard against being satisfied with less than incontestable evidence on the subject; some axles were numbered to provide this incontestability and, at the same time, be used to provide some indication of quality. It could be said of that time there was:

1) acceptance of the need for safety;
2) recognition of a wear-out process;
3) recognised opportunity for life prediction;
4) the need of reliable data, and
5) a concern with quality.

These could have been classified as Quality and Health, and so it is now, except that the tools are more sophisticated and the field of operation is more vigorous, whilst the techniques extended to monitoring. These techniques are of particular concern in the Helicopter Industry following the HARP report and its recommendations regarding Helicopter Health and Usage Monitoring [1].

2. HELICOPTER HEALTH AND USAGE MONITORING

A fixed wing aircraft is supported in flight by its structure. In contrast, a rotary wing aircraft is supported by a series of rotating mechanisms, few of which can be designed in accordance with the multiple path, redundant principles used for fixed primary lift surfaces, such as wings. Therefore the helicopter imposes a particular set of design requirements to ensure that catastrophic failures can be prevented, even though the transmission system which imparts power to the rotor blades is inherently less reliable than a fixed wing.

The lift and control forces are transmitted by mechanical systems and components which are subjected to static and cyclic loads significantly greater than the actual lift forces. These arise from thrust and similar accelerating forces.

The combination of lift and control loads concentrated in one mechanical unit, i.e. the rotor head, are unlikely to meet the expected reliability criteria for flight operations. Reliance cannot be placed only on certification testing, on safe lives derived from assumed operational use, or on life extensions based on in-service experience with accumulated flight hours.

It is important to recognise that failure is not necessarily always a function of age or time. This means that health and usage monitoring has to be applied throughout the life of all critical components and systems.

The Helicopter Airworthiness Review Panel (HARP) of the UK Civil Aviation Authority has made a number of important recommendations intended to improve the safety of helicopter operations. [1].

Among a number of recommendations made by HARP were; helicopter manufacturers, in association with operations, should apply more vigorous and extensive analysis of component lives and, in particular, relate their findings to the actual flight profiles and phases used by individual helicopter operators. Also of importance, more attention should be paid to the subject of change of use, i.e. predicted component lives and inspection periods and techniques may no longer apply when an operator starts using a helicopter on entirely different types of flight operation.

Another recommendation concerned the acquisition of in-flight recorded data of actual loadings and duty cycles obtained from realistic helicopter operations.

Other HARP recommendations concerned the publication of an Establishment and Maintenance of Quality Control guide as well as condition monitoring systems and a list of parameters to be measured.

Smiths Industries has been involved in the development and production of health, usage and performance monitoring systems (HUMS) for aviation, and marine gas turbine and transmission system for over 20 years. The Low Cycle Fatigue Counter (LCFC), a usage monitor, has been applied to engines of the Hunter, Harrier, Jaguar, Trident, TriStar, Buccaneer and Tornado. The Hawk aircraft of the RAF's Red Arrow display team provides an extreme application of a low cycle fatigue system because pilots of these aircraft have to make frequent changes in engine thrust in order to maintain station throughout their complex programmes.

In recent years SI has completed a number of HUMS development programmes for both fixed wing and rotary wing aircraft. The incidence of helicopter mechanical failures in the past two years has highlighted the need for a more extensive study of the problem and the urgent need to meet the HARP recommendations referred to above.

One of these programmes involved Westland Helicopters using a WG30-300. An on-board HUMS monitored and analysed the following parameters:-

From the engines

* power performance index
* low cycle fatigue
* thermal creep
* limit exceedence (speeds and TET)

From the transmission

* Torque usage
* Diagnostic vibration
* Quantitative wear debris monitors

An extension of the WG30-300 HUMS programme is being evaluated which will cover Rotor Head parameters such as:

* usage of torque, strain, major cycles and flying hours
* head moment - monitor and display.

An more extensive flight programme is being undertaken with an on-board HUMS in the Super Puma A332 in co-operation with Aerospatiale, Bristow Helicopters Ltd and the CAA (UK). The Smiths Industries HUMS is the Type 0852 KEL, as shown in Figure 1.

The Super Puma HUMS development programme is directed at achieving a system which will find defects before they occur in flight. Accurate health usage information is being sought in relation to engine life, health, low cycle fatigue damage, as well as life and torque usages of main and tail rotor transmissions. A further requirement specified the display of over-torque, over-temperature and overspeed in the cockpit.

Although secondary to the safety aspects of HUMS, helicopter availability has to be kept at and above a specified level. This can be achieved by refinements to maintenance schedules and by enhanced fault diagnosis. In turn these have a direct effect on operation costs and capital investment.

The HUM computer, using inputs for computation of the parameters listed above, monitors and records the data. The non-volatile data is downloaded using a Data Transfer Unit (DTU) which in turn downloads to a Maintenance Centre Analyser (MCA).

An extension of the mid-1987 HUMS programme is directed at crack propagation detection. Westland Helicopters has devoted a number of years to its development of gear-fracture analysis technique using an array of vibration pick-offs mounted on the main rotor gearbox.

The high capacity and fast digital computing of the Smiths Industries HUMS permits rapid signal averaging. Enhancement of the signal removes unwanted data, while quantification of the resultant waveform by statistical methods provides indications of crack propagation in gear wheel teeth.

3. NEEDS AND RESPONSIBILITIES

It is the joint responsibility of the helicopter operator, the constructors (airframe and engines), and the certifying authority to arrive at a means of increasing the safe life of the helicopter, as recommended by the HARP report [1]. These means can be provided by application of the HUMS.

The Health Monitoring function of the HUM is the monitoring of continued health by the detection of the precursor of the an unanticipated failure, or the onset of ill health. Similarly, the Usage Monitoring function totalised the incremental consumption of the safe life of a component as it functions. It is without question that there is a need to prevent catastrophic failure and at the same time to make economic use of major/costly components; at first sight contradictory requirements. The certifying authority has indicated the benefits which will accrue as a result of the approval and adoption of HUM practices [3,4] thus satisfying the needs of the operator and constructors. This however is accompanied by defined responsibilities [3,4], the responsibility of the certifying authority to confirm compliance with Safety Assessment criteria and that means of preventing failure of a Critical Part have been provided. The responsibilities of the constructors are to establish the basis of the claim (on airframe and power plant) and to validate it on a periodic basis, and to recommend means of detecting deterioration. The operator has reciprocal responsibilities; to generate a programme based upon the constructors' recommendations and agreed with the certifying authority; to report findings to the constructors, and to publish details of the programme. These details are to include the techniques and methods of data collection, interpretation and implementation. An effective Health Monitoring programme is quoted as requiring management commitment; the availability of facilities, associated skills and techniques; the definition of responsibilities to ensure timely analysis and implementation of corrective actions.

The text proposed [4] for British Civil Airworthiness Requirements, Section G-Rotorcraft, includes the following.

> *   HEALTH MONITORING   Where credit is claimed for Health Monitoring techniques in establishing compliance with the Safety Assessment criteria, the design of the rotorcraft shall provide for the application of such techniques.
>
> *.1   Critical Parts whose failure cannot be reliably controlled by normal lifing techniques, because the failures are not directly time/cycle related, shall be designed to have damage tolerant characteristics and for such parts an effective Health Monitoring technique shall be established.

*.2 For Critical Parts where failure can be controlled by normal lifing techniques, a Usage Monitoring technique shall be established to provide for monitoring deterioration in service, such as to confirm that the substantiation of the declared life remains valid.

*.4 In establishing the airworthiness credit for Health Monitoring the reliability of the Health Monitoring equipment shall be taken into account.

It was recognised in 1984 (Issue 1, CAA Paper No. G811) [3] that the desired level of safety was unlikely to be provided for the Rotor/Transmission System without the use of Health Monitoring. A supplement to Chapter G4-9 of Section G (Rotorcraft) was proposed for the implementation of HUM procedures, and in particular the acceptance of Health Monitoring when Usage Monitoring could not be applied, as in bearings, due to the random nature of the failure.

4. MODULAR APPROACH

There is at present a requirement by ICAO for the fitting of helicopter Accident Data Recorders (ADR) by 1st January 1989.

Helicopters with a maximum AUW of more than 2700 kg are currently required to carry cockpit voice recorders.

There is a forthcoming FDR requirement [5] for the recording, or on-board automatic analysis, of some 12 parameters on helicopters with an AUW between 2700 and 7000 kg. There is a similar requirement for some 30 parameters for AUW's greater than 7000 kg.

There are at this time at least 6 types of production helicopter within each of the above two classifications, i.e. 12 in all, manufactured by 7 constructors. Between them, they utilise 9 different types of engine, only 1 is fitted with one engine, by 6 different engine manufacturers.

It is obvious that no one system will suit all or even a large proportion of the applications. If each is unique, it is the operator, and eventually the traveller, who will pay the cost. Under these circumstances, a Modular HUMS is the only reasonable solution, that is a system which has some flexibility by application, one which results in a design particularly suited to the application by the most economical and reliable means.

5. THE MODULAR SYSTEM

The techniques used in a HUMS depend entirely upon the specification produced by the operator, following recommendations by the constructors. It should be borne in mind that much of the detailed information provided by the airframe and engine constructors is proprietary and should be treated as such. The modular HUMS has functional flexibility and can be considered to be modular by application, since the system can be built upon a core, for a particular application, from a number of modules.

The basic HUMS, shown in Figure 2, consists in essence of three modules, a HUM, a hand-held DTU with read-out and an ADR. Installation and Operation of an ADR is mandatory after January 1989. The voice recording facility is to be provided in a helicopter carrying 10 passengers or more, or weighing more than 2700 kg.

After due consideration of the remote necessary for service of the HUM, with its high MTBF, in comparison with the overhaul period of the mechanical ADR, it is impossible to justify the contention that the two facilities be combined in a single unit. The only circumstance under which this could be justified would be if the ADR had a solid state memory.

A comprehensive HUMS, shown in Figure 3, might consist of the eight modules, as follows:

1) Health and Usage Monitor

2) Data Transfer Unit

3) Accident Data Recorder with Voice Recording

4) Quick Access Recorder (QAR) with Removable Cartridge

5) Cockpit Display Unit

6) Cockpit Failure Warning

7) Track and Balance Processor

8) Maintenance Centre Analyser

Each communicates or receives data through an RS422 interface, although an ARINC 429 could be used for the exchange of external data.

The MCA accepts data from both the QAR plug-in cassettes or the DTU. It would comprise:

1) A keyboard to enable the operator to select data for viewing and to add information to the data base.

2) A VDU to display data either graphically or numerically.

3) A printer to enable data, numerical and graphic, to be produced on hard copy.

4) A removable bulk-storage medium to permit data to be archived and retrieved.

5) Serial interface for communication with the DTU.

Some of the range of acceptable inputs, computational features and outputs, or displays, are shown in Figure 4, in the Outline of Input and Computational Flexibility of the HUMS.

6. THE MODULAR MONITOR

The HUM, to be seen partly dismantled in Figure 5, is modular in construction. It is dimensionally to ARINC 600 and it meets the relevant requirements of DO160. The 4 MCU size of units ($^1/_2$ ATR Short) were designed for the WG-30-300 and the A322 to meet the helicopter vibration requirements by the use of stiffened circuit boards. Those fitted to the 3 MCU size of unit ($^3/_8$ ATR Short) for the 0826 KEL, for the BAe 146, were unstiffened and met the fixed wing requirements.

The boards are completely interchangeable and provide for the variety of input signals which are met in practice. It is by this means that a wide range of options is available in this type of modular HUM, particularly since the largest size, 6 MCU ($^3/_4$ ATR), accepts twelve circuit boards.

The use of standard boards and standard cases results in economy and reliability in both the helicopter and the fixed wing applications.

7. LIFE CYCLE COSTS

Life cycle costing (LCC) provides a means of determining whether fleet wide installation of HUMS is cost effective, or the saving which must be made to make it cost effective [6]. This is determined by comparing the reduction in LCC of the aircraft with that of the HUMS. One notable result of the fleetwide installation of the 0301 KEL LCFC in the RAF Red Arrow aerobatic team (BAe Hawk) was said to have resulted in a reduction in engine-related part consumption by at least 20%. The aircraft were in addition used more effectively over their scheduled life. There were also savings in the cost of maintaining engineering records and maintenance schedules, and in engine testing, together with the cost of fuel. Against these gains would be set the LCC of the LCFC, based upon:

1) cost of acquisition and spares;

2) installation;

3) operation and support;

and

4) life of the equipment.

ACKNOWLEDGEMENTS

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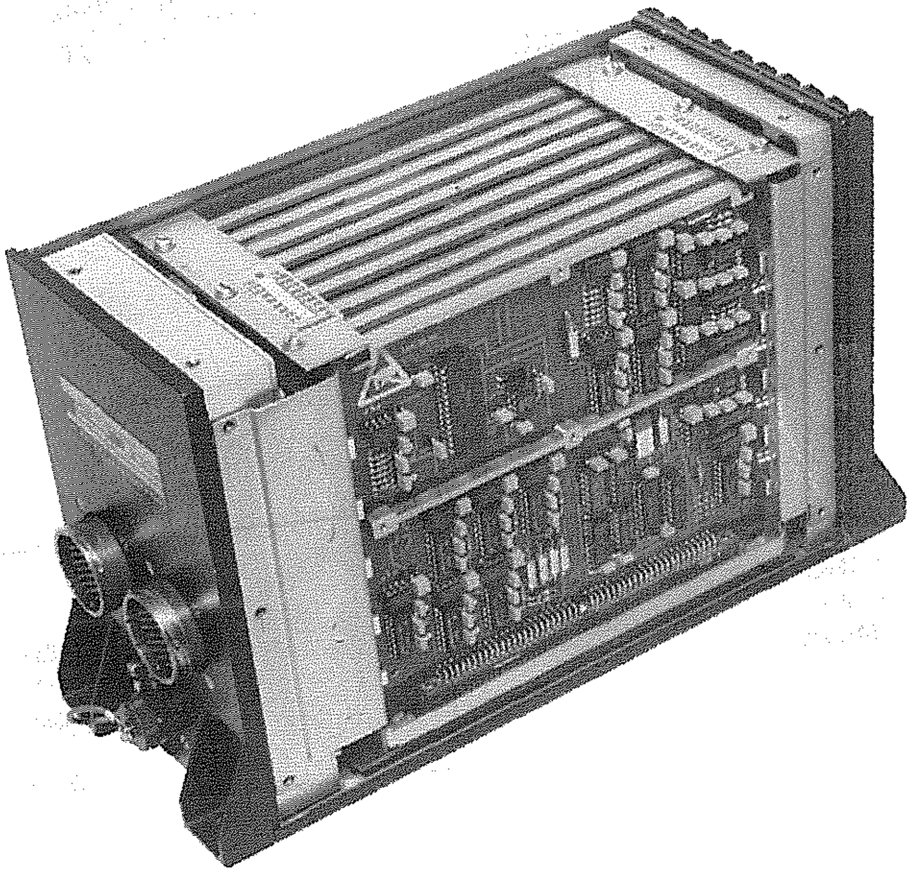
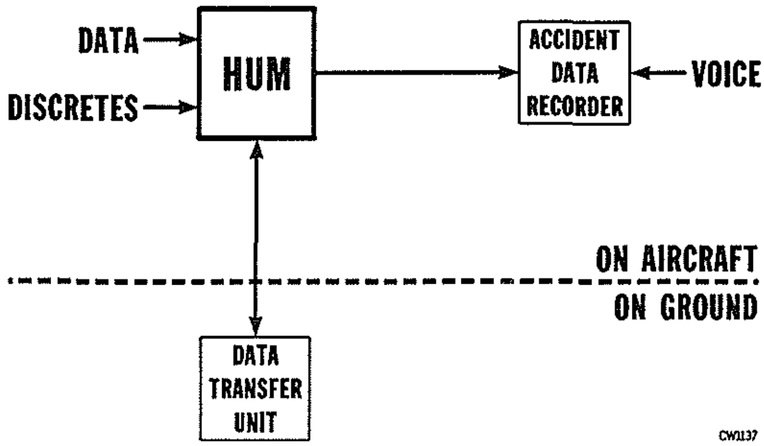
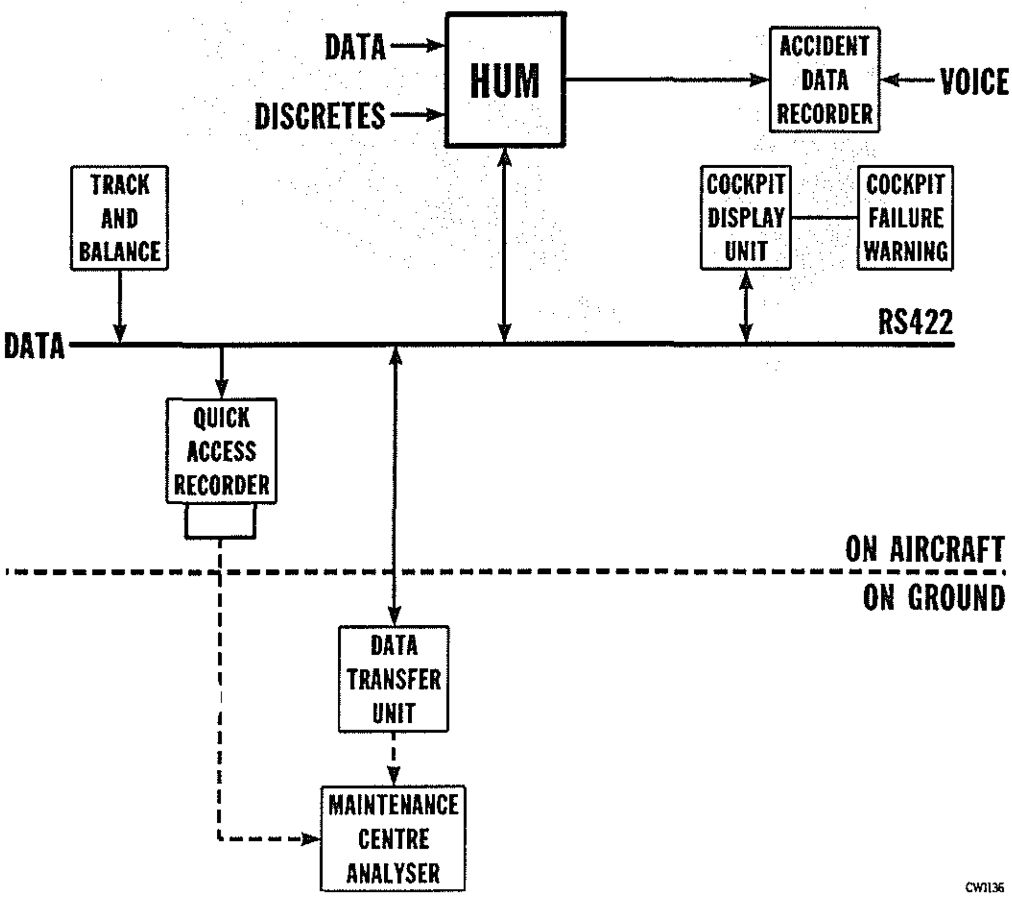


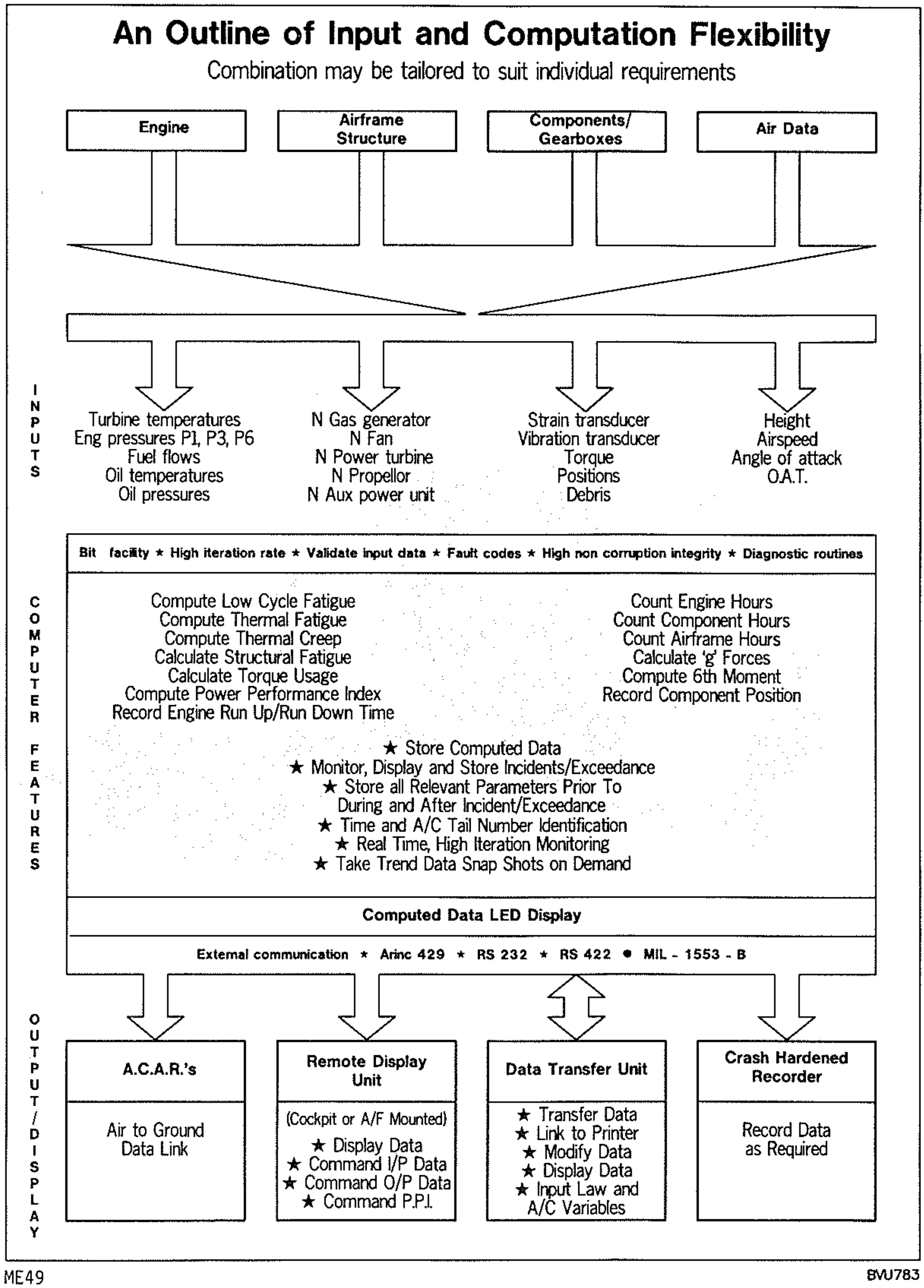
HUMS Type 0852 KEL
Figure 1



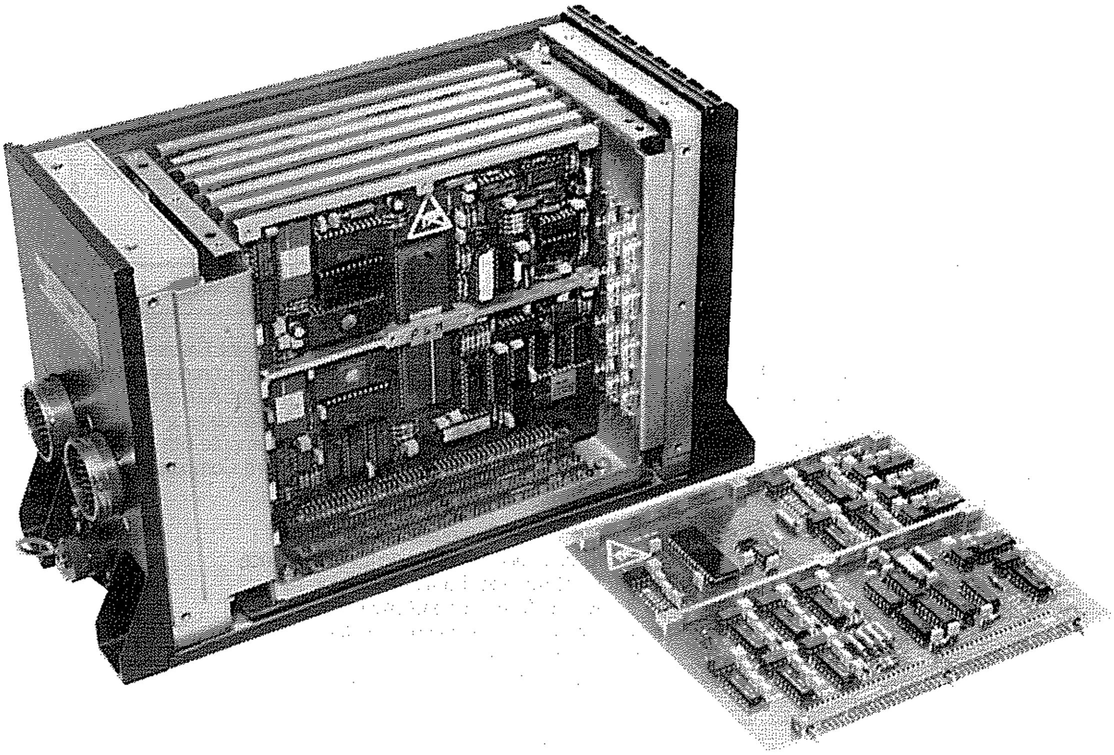
Basic HUMS
Figure 2



Comprehensive HUMS
Figure 3



Outline of Input and Computational Flexibility of the HUMS
Figure 4



Partly Dismantled HUMS Type 0852 KEL
Figure 5