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Monitoring the EJ200 Engine

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Summary

The EJ200 Engine Control and Monitoring System provides a comprehensive functionality to fulfil the engine's testability, failure localisation, and other monitoring requirements. This is shared by several devices:

- the Digital Electronic Control Unit supervises its hardware and other engine control system accessories, and detects engine incidents with a direct impact on engine operation,
- the Engine Monitoring Unit reports all incidents and defects, and monitors engine performance, vibration, life usage of engine components and oil debris,
- the Ground Support System performs further analyses, data base management and organises data transfer from and to the on-board systems.

This report gives an introduction to the various functions and to the interactions.

Die Überwachung des Triebwerks EJ200

Übersicht

Das Regel- und Überwachungssystem des Triebwerks EJ200 verfügt über umfangreiche Einrichtungen, um die Forderungen zur Testbarkeit, Fehlerlokalisierung und zu anderen Überwachungsfunktionen zu erfüllen. Sie sind auf mehrere Geräte verteilt:

- der Digitale Triebwerksregler überwacht seine Hardware und andere Regelungskomponenten und erkennt Triebwerksvorfälle, die den Triebwerksbetrieb beeinflussen,
- die Triebwerksüberwachungseinheit teilt alle Vorfälle und Ausfälle mit und überwacht Schwingungen, Partikel im Öl, Triebwerksleistung und Lebensdauerverbrauch der Triebwerkskomponenten,
- Das Bodendienstsystem führt weitere Analysen durch, verwaltet die Datenbank und wickelt die Datenübermittlung von und zu den Bordsystemen durch.

Dieser Bericht gibt eine Einführung in die verschiedenen Funktionen und Zusammenhänge.

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List of Abbreviations

AETS	Advanced Engine Testability System
BIT	Built-In Test
CPU	Central Processing Unit
DDL	Digital Direct Link
DECU	Digital Electronic Control Unit
ECMS	Engine Control and Monitoring System
EF	Eurofighter
EJ	Eurojet
EMU	Engine Monitoring Unit
GSS	Ground Support System
IPU	Interface Processing Unit
LCC	Life Cycle Costs
LVDT	Linear Variable Displacement Transducer
MDP	Maintenance Data Panel
NH	High pressure spool speed
NL	Low pressure spool speed
PMDS	Portable Maintenance Data Store
PROM	Programmable Read Only Memory
RAM	Random Access Memory
RVDT	Rotational Variable Displacement Transducer
T2	Engine entry total temperature
T3	High pressure delivery total temperature

1. Introduction

FiatAvio of Italy, Industria de Turbo Propulsores (ITP) of Spain, MTU of Daimler-Benz Aerospace in Germany and Rolls-Royce in the United Kingdom formed EUROJET Turbo GmbH to design, develop, manufacture and support the new generation EJ200 engine which powers the most advanced combat aircraft, the Eurofighter 2000.

EJ200 is a two spool, reheated turbofan engine designed with a bypass ratio of about 0.4, an overall pressure ratio of about 26:1, and a sea-level static thrust around 90 kN. The engine, fully modular, is designed for on-condition maintenance.

The design objectives with EJ200 are shown in Fig. 1. The prevailing argument behind most objectives has been to develop a highly cost-effective engine. Much attention has been given to reduce the overall Life Cycle Costs (LCC). Cost-effectiveness strongly depends on engine availability. The EJ200 Engine Control and Monitoring System (ECMS) provides the testability and monitoring functions for reducing maintenance hours, for improving engine availability and operational reliability and thereby reducing the major element of LCC, the in-service costs. ECMS includes a full-authority Digital Electronic Control Unit (DECU).

ECMS provides a thrust-rating feature which enables full use to be made of the life potential of an individual engine. This will further reduces LCC. ECMS will automatically record all detected incidents. This contributes to a reduced pilot workload.

ECMS has been designed as an integral part of the Integrated Monitoring and Recording System (IMRS) and of the Integrated Testability System (ITS) of the whole EF2000 aircraft. ECMS is linked to the aircraft on-board maintenance systems and using these systems will report and communicate with the ground crew.

2. Engine Monitoring Requirements

The main monitoring-related requirements to be fulfilled or supported by the ECMS are to

- detect and compensate for control system defects
- detect and transmit to the aircraft cockpit the occurrence of significant engine malfunction
- provide engine usage, health monitoring and maintenance data to the external interfaces
- allow more detailed long-term analysis of captured monitoring data
- fulfil the on-aircraft quantitative testability requirements

ECMS functionality aims to decrease the rates of mission aborts and engine shut downs by the detection and accommodation of failures. Quantitative testability requirements specify the rates of failures to be detected, and the rates of failures to be located to a given small maximum number of items, or to a single item, respectively.

3. EJ200 Engine Monitoring - An Integrated System

The Engine Monitoring Unit (EMU) represents the central processing element for EJ200 engine monitoring in respect of the EF2000 aircraft application. The EMU is air-cooled and mounted in the aircraft avionics bay (Fig. 2). It comprises of two essentially identical and separate lanes for monitoring the two engines powering the EF2000 aircraft.

The EMU is dedicated to engine monitoring functionality but also the DECU - although principally engaged with engine control - plays an important role in acquiring monitoring data. Both are linked via a dedicated bi-directional digital data bus.

The DECU is engine mounted and fuel cooled. It consists of two identical lanes, communicating via an internal interface. Thus each lane has available the input signals to the other lane. Each lane is informed about the operational status of the other lane. Either lane will be used for engine control. There is no preferred lane.

The basic function of the DECU is to control the engine dry and reheat fuel flows, nozzle area and variable guide vane angle in response to thrust demands, and to ensure that the engine functions throughout its operating range within the permissible flight envelope without exceeding any limitations. In addition Built-In Test (BIT) functions are implemented to determine the engine control system health and to enable graceful functional degradation in the event of defect.

While the DECU is the source of cockpit warnings, the EMU is the proper unit to collect and to transmit all data to the appropriate aircraft systems for maintenance and post-flight analysis (Fig. 3). Amongst other information the EMU exclusively reports all incidents and failure diagnoses to the aircraft Interface Processing Unit (IPU) for on-board indication on the Maintenance Data Panel (MDP) and for transmission to the Ground Support System via the Portable Maintenance Data Store (PMDS). The EMU also supplies, via the IPU, engine data to the Crash Survival Memory Unit and to the Bulk Storage Device. This item provides storage of selectable data for special investigations.

4. Digital Electronic Control Unit Monitoring Functions

Fig. 4 includes an overview on the DECU and its associated control system components.

4.1 DECU Built-In Test

Electronic components involved in engine control are a principal and vital part of the engine. These components are directly linked to and monitored by the DECU. Due to comprehensive BIT (Tab. 1) a high operational reliability and fault tolerance is achieved.

DECU Initiated BIT	DECU Continuous BIT
DECU memory (RAM, PROM) *) Address line (RAM) *) Real-time clock and interrupt logic *) Interface calibration Watchdog timer and reset logic Hardware/software failure flag (lane selection / deselection) Analogue overspeed governor *) also checked during Continuous BIT	Sensor failure detection (model, range, cross checks) Discrete input signal check External bus supervision DECU computer check (CPU) Solenoid supervision (open/short circuit) Ignitors Actuators (model, LVDT/RVDT sum)

Tab. 1 DECU Built-In Test

Initiated Built-In Test mainly provides detection of DECU hardware failures. Special test circuits are activated. Initiated BIT is performed when the aircraft is on ground prior to and after engine operation, and on request from the Maintenance Data Panel (MDP).

Continuous Built-In Test accomplishes the detection and localisation of failures of the system during engine operation.

The DECU categorises the severity of the failures. The lane in control decides whether to take a signal from the neighbouring lane or whether to perform a lane change.

4.2 Incident Detection and Pilot Indication

There are several classes of engine incidents detected by the DECU: those requiring recovery by the control system, engine health indications to the Flight Control System / cockpit, control status messages, and engine malfunction. All incidents are provided to the EMU for recording.

The DECU detects engine incidents requiring recovery actions from the control system. There are safety and timing reasons to do this within the control unit:

- higher software risk class level of the DECU compared to the EMU due to control demands
- no delay from transmission between EMU and DECU

- high iteration rate / high resolution of time signals by the DECU

Some of these incidents are derived from special sensors like jet pipe resonance. Others, like engine flame out, are derived from the same sensors as used for engine control.

Many of those incidents having an impact on engine control require cockpit indication. The DECU is directly mounted on the engine and linked to the cockpit via the dual redundant Flight Control System bus. The DECU also identifies incidents from the fuel, oil and hydraulic system (impending filter blockage, low pressure, low level, high temperature). The only incident detected by the EMU and routed to the cockpit via the DECU is vibration warning.

Failures detected by DECU BIT which result in a DECU lane change, in a reversionary control or even lead to a loss of control, are indicated in the cockpit and are considered as incidents.

The DECU also monitors for instantaneous severe performance deterioration. If detected before take-off the DECU will provide a cockpit warning.

5. Engine Monitoring Unit Functions

An overview of all engine monitoring functions is depicted in Fig. 5.

5.1 EMU Built-In Tests

The EMU performs Initiated and Continuous BIT on its own hardware and on its associated external devices, i.e. on the front and rear vibration sensors and on the Oil Debris Monitoring system.

5.2 Engine Performance Monitoring

Performance snapshots

The EMU includes a logic to sample snapshots of smoothed engine parameters together with flight parameters at selected conditions. A special selection criterion is specified to identify the rating snapshot which is the „highest stabilised condition“ per flight and which is used for thrust rating.

Thrust Rating

Engine performance monitoring on EJ200 is not a passive monitoring feature. There is a feed back to engine control: a self-learning system tunes the speed and temperature limits for thrust rating. This is automatically performed with the rating snapshot and a flight-to-flight trending mechanism.

„Thrust rating“ means that available thrust at max dry conditions will be kept constant for the engine life period. Temperature and speed limits will be reduced for an engine providing thermal margins thus saving engine life. Normally, limits will continuously increase when the engine deteriorates to keep the available thrust at a constant level. If the engine reaches a cleared limit maintenance is required. Trim offsets are transmitted from the EMU to the DECU which takes special precautions not to corrupt the control system safety.

Sudden Engine Deterioration

Thrust rating functionality monitors continuously slow and progressive engine deterioration. On-board detection of sudden and significant deterioration is also required. Symptoms eventually resulting in a No-Go cockpit warning are identified by the DECU. Other effects resulting in reduced engine performance are monitored by the EMU. This is done mainly to provide the Advanced Engine Testability System (AETS) function with additional information to detect and localise system failures.

5.3 Vibration Monitoring

EJ200 is fitted with two accelerometers: one mounted at the front, the other one at the rear part of the casing.

Experience from previous engines has been taken into account for EJ200. There is an on-board detection of high broadband vibration level, imbalance in high pressure and low pressure parts, isolating whether compressor or turbine parts are affected. Further vibration modes can be programmed according to demands. During engine operation each mode is compared with self-learned datum signatures to detect a relative increase in vibration requiring maintenance. High absolute vibration levels are signalled directly to the pilot who can take appropriate action.

The EMU reports to the Maintenance Data Panel MDP about the level of exceedance, the kind (high or low pressure spool affected) and the location (front or rear). Spool speed dependent datum and maximum amplitudes and time signals are collected and transmitted to the GSS. They are tagged with flight parameters to enable the external influence of aircraft-induced effects to be isolated. This permits to analyse further vibration modes on ground and to build up a data base targeting to describe more vibration incident patterns for future on-board fault isolation [1].

5.4 Life Usage Monitoring

In-service experience has been gained from a similar system used for the RB199 engines in the German Tornado aircraft fleet. Various aspects of life usage monitoring have been discussed in previous publications by MTU [2, 3]. Another application is currently being implemented on MTR390 engines [4].

Conventional life usage monitoring is based on engine flying hours and / or number of flights. It has been demonstrated that the system applied will double the average usage time without any loss in safety. There are various and complex effects for why conventional life usage monitoring concepts fail [2]. The variety in “mission types” is only one effect - and may not even be the most important one.

The EMU will individually monitor the total life of the engine’s critical parts with respect to the prevailing damage mechanism. This is performed on board in real-time with a high accuracy. Temperature distribution and stress models are tailored to use already available engine signals (engine speeds, temperatures, pressures) - no sensors dedicated to life usage monitoring are installed. EMU employs state-of-the-art approaches to quantify low cycle fatigue, thermal fatigue and creep damage which are the mechanisms currently identified for those parts.

The engine modules which are life monitored are listed in Tab. 2. The first area of a module to reach its released life determines the whole part’s life. However, there may be several areas on the same part that might fail at first depending on the operational use. The number of areas listed

Part	Initial number of monitored areas	Damage mechanism
Low pressure compressor	14	Low cycle fatigue
High pressure compressor	34	Low cycle fatigue
Combustor casing	2	Low cycle fatigue
High pressure turbine	2 (blades)	Creep, thermal fatigue
	13 (other)	Low cycle fatigue
Low pressure turbine	1 (blades)	Creep
	8 (other)	Low cycle fatigue

Tab. 2 Life-Monitored Parts of EJ200

in Table 3 will be reduced in future with some in-service experience. The target is to identify all potentially life-determining areas and to discard all other areas from being monitored.

In addition statistical data which illustrate engine use are provided. A usage spectrum function assesses histograms of several engine parameters. A counts and times function provides statistics like the total number engine runs, total running time, number and duration of reheat selections per flight / totally, etc.

5.5 Oil Debris Monitoring

The purpose of the Oil Debris Monitoring is to provide data about the quantity of metal particles that have been captured from the engine lubricating oil, to allow early detection of bearing / gear failures [5].

A magnetic sensor is mounted in the main scavenge return. It captures ferrous debris in the oil and thus acts also as a master chip detector. It is provided with an electrical coil, part of a resonant circuit. An engine-mounted unit houses the rest of the resonant circuit and the associated electronic items. In this unit there are also the electronic signal conditioning parts. It communicates with the EMU via a Digital Direct Link (DDL).

The sensor provides a signal corresponding to the collected mass that is monitored continuously by the system. It will be able to distinguish between small and large particles (chunks) that will correlate with normal and abnormal wear. A sudden increase in mass suggests that a large particle has been captured. Thresholds are increased for the initial period of engine usage to cope with increased rates of collected debris expected for this time period. Total collected mass will correlate with the total wear of the engine. Saturation of the chip detector is additionally indicated on condition.

5.6 Incident Monitoring

Incident Monitoring will provide information on identified abnormalities that have happened during recent flights. ECMS provides a list of more than 60 possible incident types that are input to a common incident monitoring function. They typically fall into the following categories

- Exceedance of an engine parameter (speed, pressure, temperature)
- High vibration (relative to datum signature or to a predetermined level)
- Airflow problems (surge, stall, jet pipe resonance)

- Engine control status (automatic lane change, actuator malfunction, or even loss of control)
- Engine malfunction (start abort, reheat selected not lit, engine flameout)
- Oil and fuel system related status messages (low oil pressure, high temperature, impending filter blockages, oil debris saturation)
- Oil debris incident (high rate of oil debris mass accumulation, high number of chunks)
- Performance related events (low thrust symptoms)
- Pilot-initiated events (control lane change, incident snapshot)
- Low remaining engine life (post flight detected)

Another classification can be made as follows according to the incident's priority
- Alarms reported to the pilot which may affect the mission; immediate maintenance required in most cases
- Incidents not reported to the pilot; resulting in maintenance actions only
- Pilot-initiated events (control lane change or incident snapshot; on ground analysis required)
- Informal events (vibration datum store filled)

An <u>incident summary</u> will describe each incident that occurred. An intensity will be calculated for each incident to assess priority. It depends on the incident type, on the incident duration and on the relative exceedance.
- What was the dominating incident type / which other types of incident accompanied it ?
- When did the incident happen ?
- How long did the incident last ?
- What was the peak value (if the incident was an exceedance) ?
- What was the intensity ?

Most of the in-flight incidents will additionally trigger the <u>incident snapshot</u> function storing the history of all engine signals for a period from 10 sec before to 20 sec after the incident. Up to 50 summaries and 5 snapshots can be gathered where the incident intensity will be used for priority management. The MDP will provide an overview on incidents after flight.

[6] gives an overview on incident monitoring considering EJ200 aspects.

5.7 <u>Advanced Engine Testability System Function</u>

In a similar way to incident monitoring the Advanced Engine Testability System (AETS) is a function to collect fault information from other ECMS functions. AETS will analyse the fault scenarios and is the place where the on-aircraft requirements for engine failure detection and

location are met. Engine availability or faulty line-replaceable items, respectively, are reported to the MDP and to the GSS via PMDS for maintenance crew action.
Electronic system component diagnosis is available from DECU BIT and EMU BIT. Failures received from BIT directly identify a defective electronic component. Also vibration diagnosis on engine imbalance is related to front or rear, high pressure or low pressure modules. For other symptoms like „loss of oil pressure“ or „low thrust“ the components likely to have failed will be indicated in the order of probability.

AETS will address more than 60 line-replaceable items identified via about 300 fault codes. The failure matrices processed by AETS are easy to update as experience with EJ200 testability grows when the engine is in service.

5.8 Configuration Control Function

The configuration control function checks actual serial, hardware or software part numbers of engine system components to ensure overall compatibility. The required configuration is loaded from the Ground Support Station. In case of configuration changes other functions will be re-configured as appropriate.

Any mismatch will be reported to the maintenance crew. In case of mismatch engine availability will be maintained and subsidiary functionality provided as far as possible.

6. Ground Support System Functions

The GSS is an essential part of the aircraft Integrated Testability System and of the engine monitoring. Generally, the engine-related part of GSS functionality performs the main functions:

- Store and present, as required, all data obtained from the EMU via PMDS.
- Evaluate trends and the time to the next predictable maintenance demand.
- Support maintenance planning and procurement of spare parts by indication of systems and modules which are going to exhaust soon.
- Provide an indication of engine readiness (Go/No-Go) with appropriate maintenance recommendations whenever a more comprehensive analysis is required than is possible with the on-board system.
- Guide and communicate with personnel for tasks to be done for failure localisation (e.g. use of additional ground eq

uipment, spectrometric oil analysis, visual inspection) in case that more comprehensive inspection is required than is possible with the on-board system

- Update and maintain engine life usage accounts, and substitute or correct data when on-board engine monitoring data is not obtainable or is suspect.
- Display incident snapshots and vibration data records; bulk storage and crash recorder data can be analysed if appropriate.
- Collect and maintain information about individual engines as electronic logbooks.
- Generate EMU initialisation data (configuration, life accounts, etc.) for uploading via the PMDS when an engine or the on-board Engine Monitoring Unit has been changed.
- Communicate with the user network and industry as required (see Fig. 6).

7. Design and Development Status

The major part of EJ200 Engine Monitoring System has now been designed and implemented. Flight testing has commenced. The system is on the way to fulfil the ultimate requirements for engine testability and maintainability. A fully integrated system has been achieved to ensure user-friendly operation with the objective to fulfil the customer expectations.

8. List of References

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[2]	Broede, J.	Design and Service Experience of Engine Life Usage Monitoring Systems. Proc. of the 5th European Propulsion Forum 5.-7. April 1995, Pisa.
[3]	Pfoertner, H. Roß, C.	Preparing Life Usage Monitoring for the Next Decade. Prepared for Proc. of the 17th Symp. on Aircraft Integrated Monitoring Systems, Stuttgart, 1995.
[4]	Richter, K.	The On-Board Engine Monitoring System of the MTR390 Engine. Proc. of the 17th Symp. on Aircraft Integrated Monitoring Systems, Bonn, 1993.

[5] Di'Pasquale, F. Greenfield, St. Development of an On-Line Oil Debris Monitor for the GE-90 Engine. Proc. of the 5th European Propulsion Forum 5.-7. April 1995, Pisa.

[6] Broede, J. Pfoertner, H. Incident Monitoring - General Requirements and First In-service Experience. Proc. of the 5th European Propulsion Forum 5.-7. April 1995, Pisa.

9. Figures

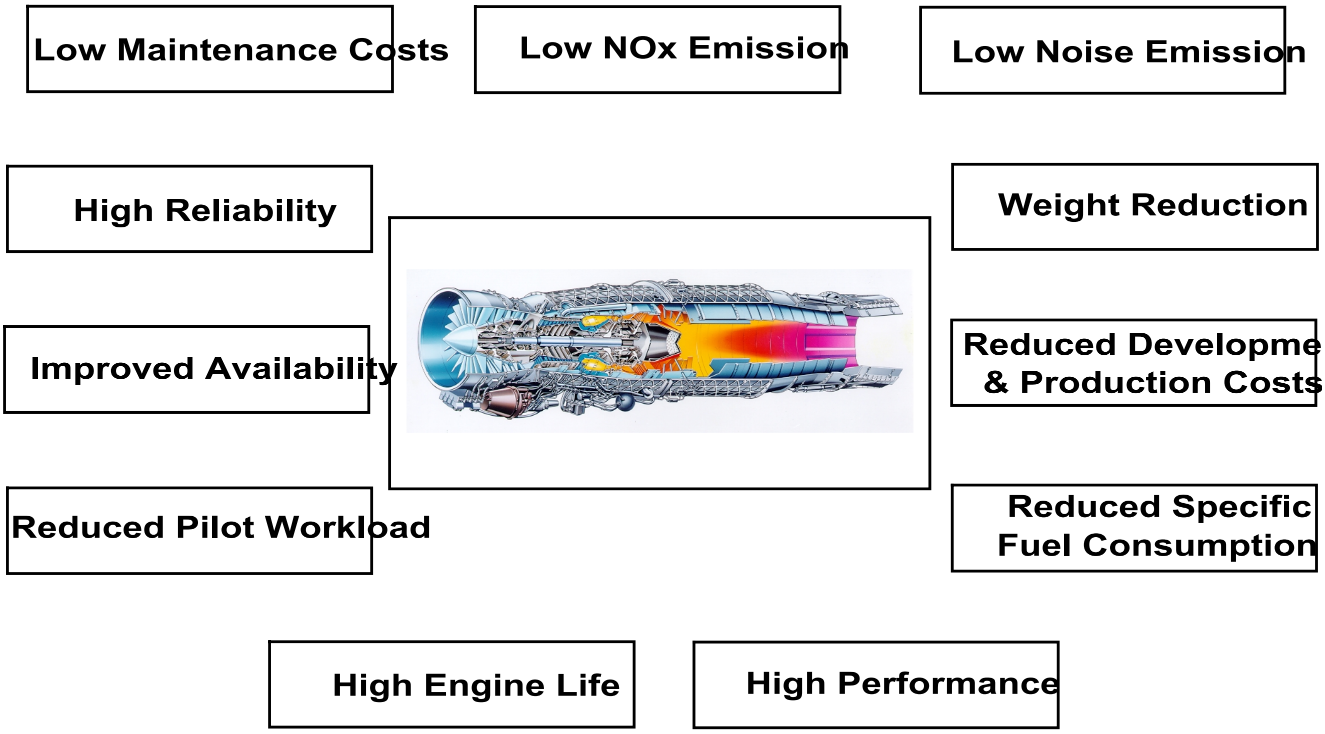

Fig. 1 EJ200 Design Objectives

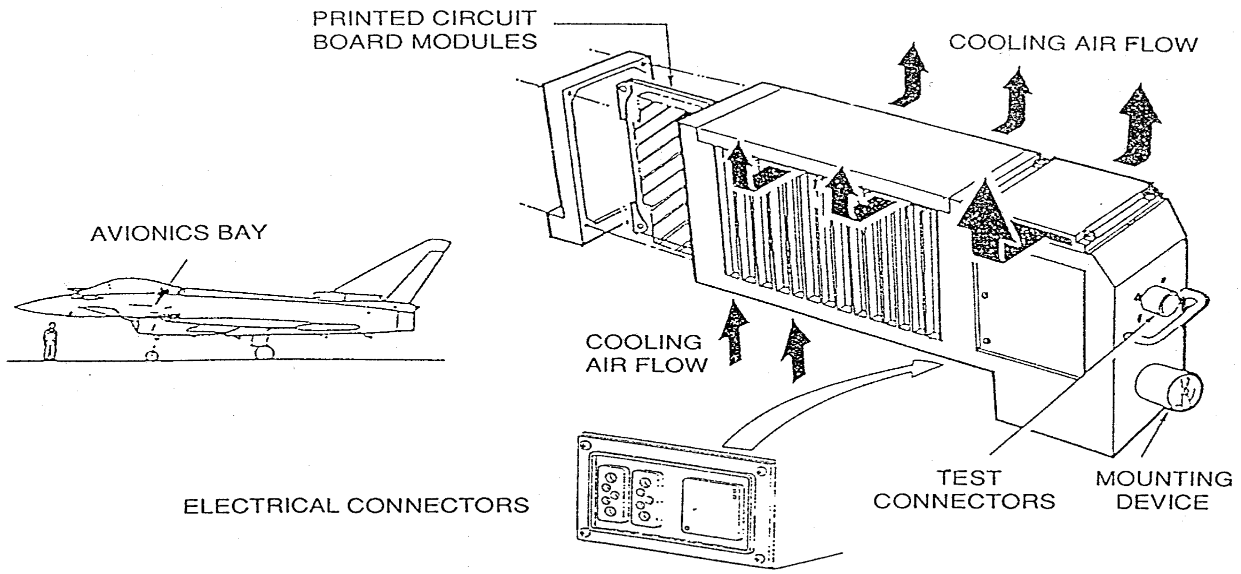

Fig. 2 Engine Monitoring Unit Installation

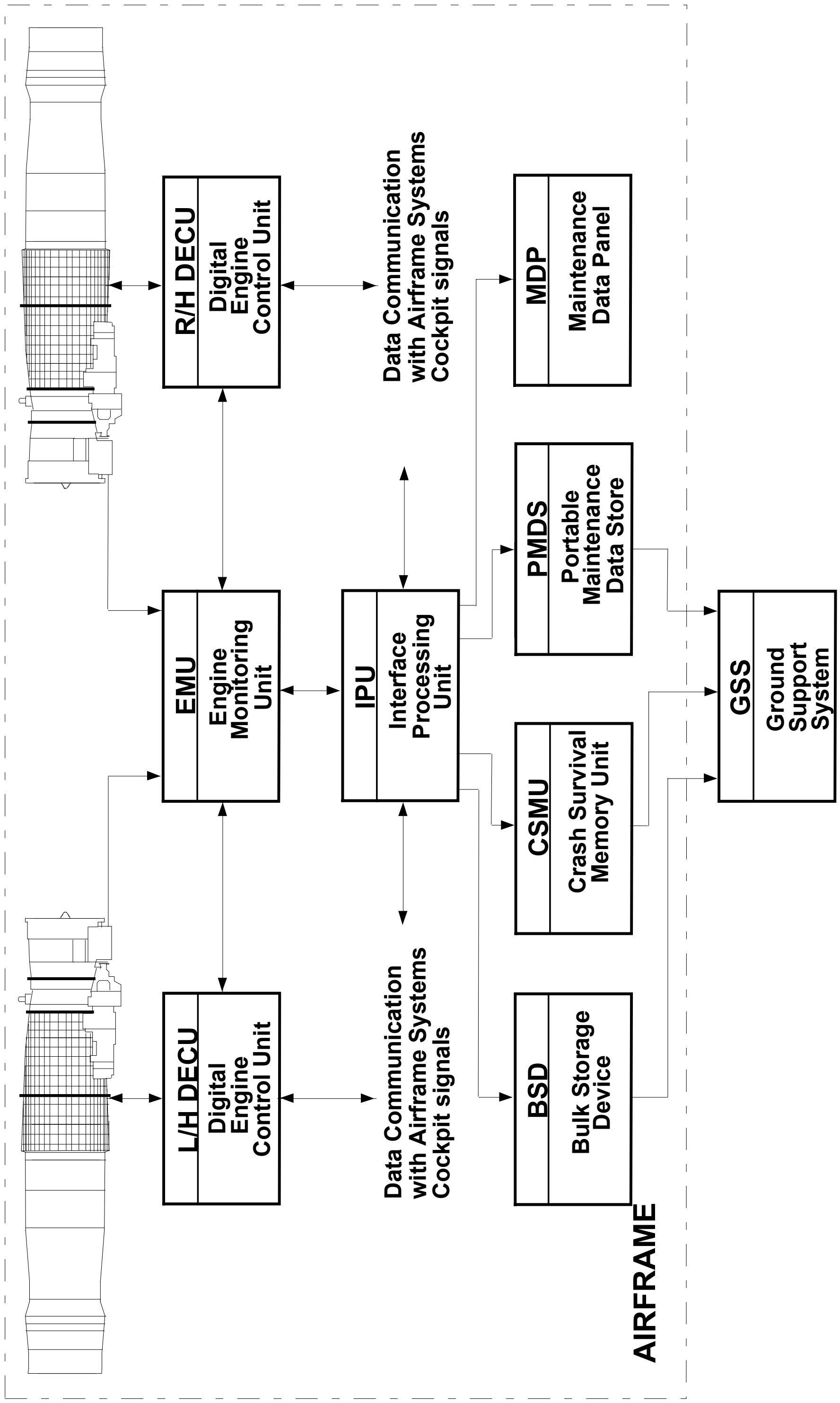

Fig. 3 Engine Monitoring System Data Flow

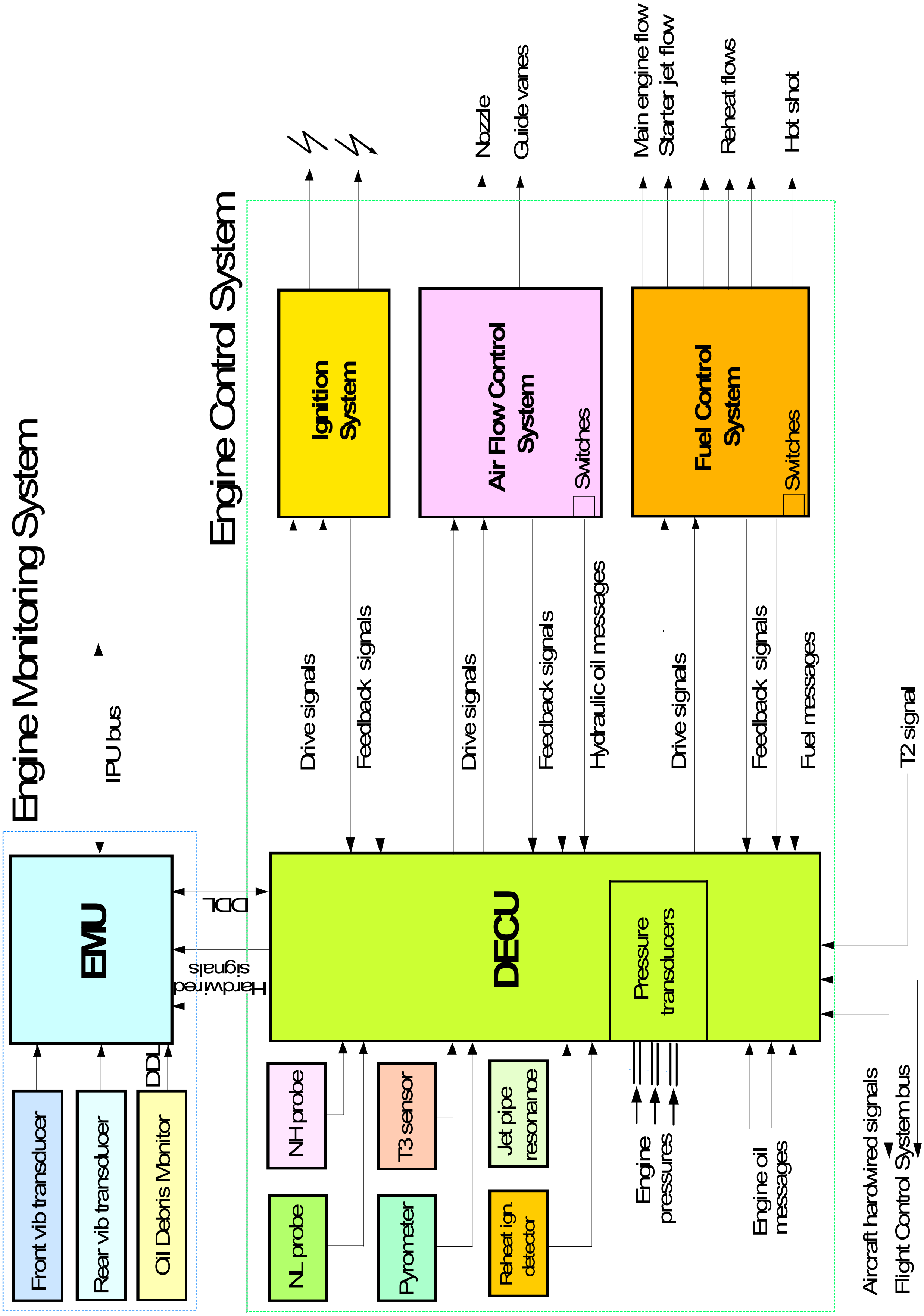

Fig. 4 Engine Control and Monitoring Units and Associated Components

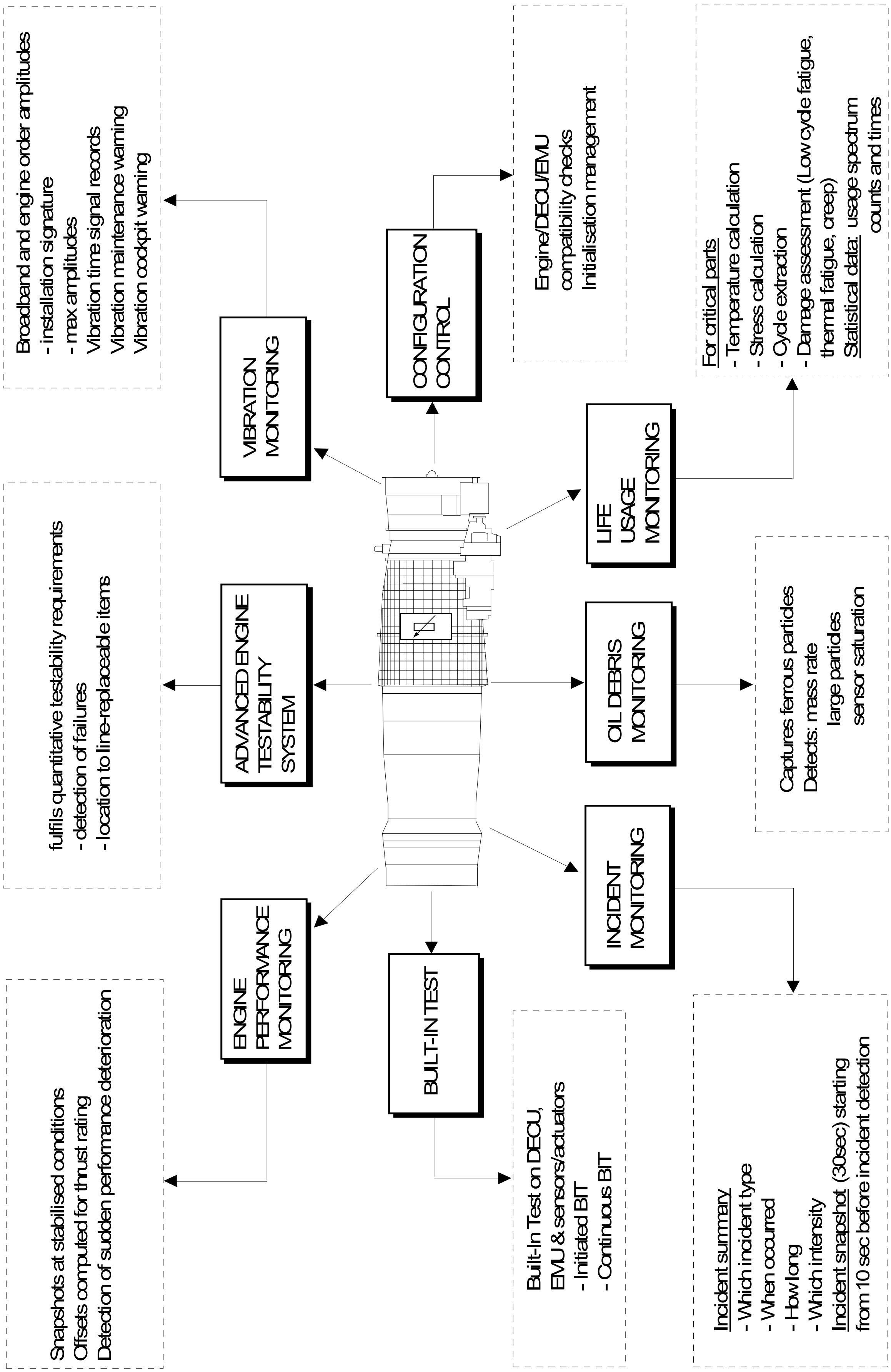

Fig. 5 Engine Monitoring Functions

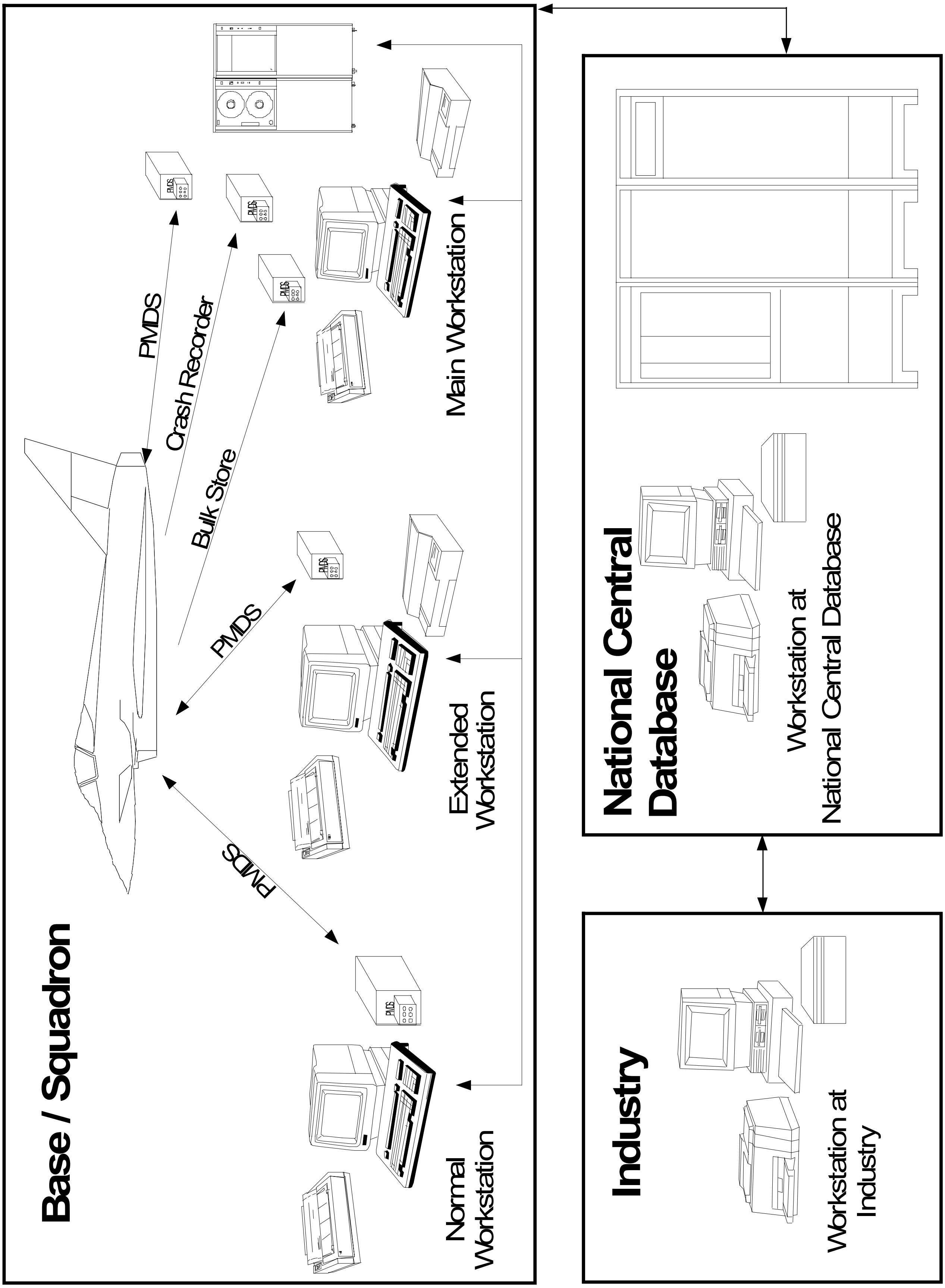

Fig. 6 Ground Support System Data Communication