AIRCRAFT CONDITION MONITORING SYSTEM (ACMS) FOR A330/A340 - NEW CONCEPT AND APPLICATIONS

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Abstract

The new generation of civil transport aircraft as the Airbus A330/A340 which are characterized by latest state-of-the-art technology and high complexity of the aircraft systems requires new solutions for efficient maintenance and monitoring concepts. The ACMS, which consists in an on board computer and recording facilities, collects data on routine basis and at exceedance of limits. It is used for trend monitoring, special investigations and trouble shooting. The system is supported by a PC based ground support equipment which allows reconfiguration of the airborne ACMS computer, programming new software and read out and analysing of the results.

The system uses the cockpit disk drive unit for uploading new s/w versions and for downloading data. Alternatively the ACMS uses the ACARS, a radio datalink between aircraft and ground, for uploading software and requests and for transmission of information of results to ground.

This paper gives an overall view of the ACMS architecture and functions with respect to an efficient air/ground transmission of the information and explains by an example the new applications and procedures which we have introduced with the A330/340 ACMS.

1. Introduction

In the past the aircraft condition monitoring was performed after flight on ground using the data which were recorded during flight on the Flight Data Recorder or the Quick Access Recorder (QAR). The QAR records the same data as the Flight Data Recorder on a magnetic tape cassette. After the flight the cassette was removed from the aircraft and the tapes were transcribed. The data was then fed into a computer on ground which then processed the information and performed an exceedance detection and trend monitoring.

The disadvantage with this procedure was, that the really interesting data was not immediately available, but with a time delay of several days or even weeks. As a consequence of this, maintenance actions could only be performed late or unscheduled.

With the introduction of an intelligent aircraft condition monitoring system, i.e. a computer within the a/c, the ACMS, a preselection of data could be performed. The ACMS continuously analyses on board the flight data in real time and allows an immediate indication of exceedance events and critical trends. This limits the amount of data which needs to be transferred to ground.

Besides collecting data for a/c condition monitoring tasks the ACMS is used as a flexible tool for trouble shooting. For this purpose it is necessary that the system is flexible enough to allow the user to select data which shall be recorded or arranged in a report and to determine the events (=start trigger logic) when recording shall start. A report is a compilation of parameters which are collected at a predefined trigger event.

To take full advantage of the potential of the ACMS it is important that the ACMS data are fast and reliable transmitted to the ground.

2. Design Objectives and System Architecture

Studies carried out and discussions together with the Airbus launching customers resulted in design objectives as follows:

* Standard aircraft and engine monitoring related ACMS functions shall be defined, adjusted and certified by Airbus Industrie (AI).

* Alternatively to the conventional cassette recorder which is the Digital ACMS Recorder (DAR), an integrated Smart ACMS Recorder (SAR) shall be designed, which records flight data in non-volatile solid state memory. Data compression shall ensure efficient memory usage.

* The amount of data which has to be transmitted from the aircraft to the maintenance center for ground analysis shall be reduced to a minimum.

* The paper in the cockpit shall be reduced to a minimum, i.e. all today's available aircraft/ground communication channels shall be used to support the ACMS.

* Entering the cockpit for ACMS programming and export of data shall be reduced to a minimum, i.e. programming of the ACMS via MCDUs and print out of hard copies shall be replaced by using diskettes and ACARS as far as possible.

* Advanced programming capabilities shall provide flexibility in definition of trigger conditions for special investigations, additional user programmable reports and selection of communication channels.

* A Ground Support Equipment (GSE) based on a personal computer shall be provided for read out and presentation of data acquired by the ACMS and DMU programming.

3. ACMS Functional Description

The ACMS mainly consists in the Data Management Unit (DMU) with an integrated 4 Mbyte SAR and in a cassette tape recorder (DAR) which is connected to the DMU. The A330/340 DMU, the central part of the ACMS, is an avionic computer optimized for high speed acquisition of digital data and associated processing. The multi tasking architecture allows parallel processing of the various condition monitoring tasks in real time, data acquisition from up to 64 ARINC-429 standard input buses and supplying the DAR and/or the SAR with data.

3.1 Aircraft Data Acquisition

Via up to 64 ARINC-429 standard input buses the DMU receives data from the following aircraft systems:

* engine and fuel control computers

* Auxiliary Power Unit (APU)

* flight control computers

* cabin temperature and pressure control computers

* navigation and flight management computers

* other avionic systems

Figure 1 gives an overall view of the system interconnections to the DMU. The DMU has access to approximately 2200 numerical parameters as e.g. altitude or exhaust gas temperature and 11000 discrete parameters which describe discrete states as the open or close state of a valve.

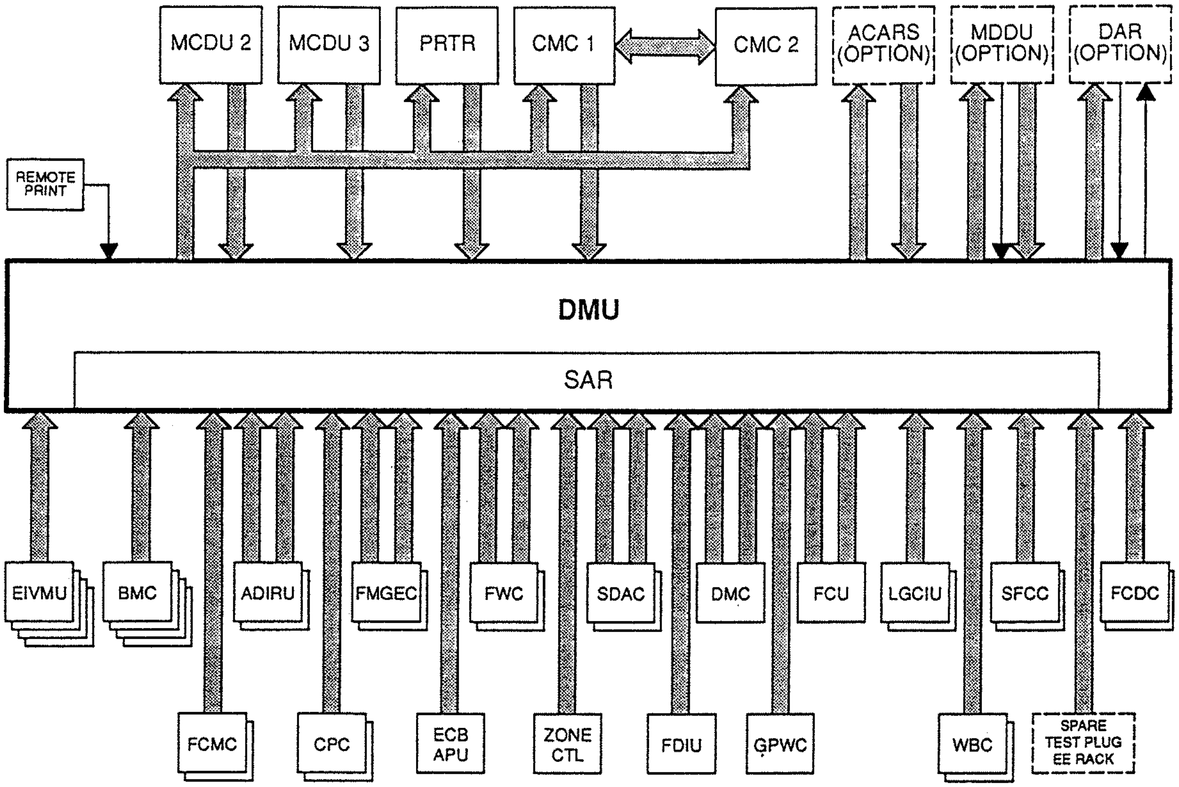

Figure 1: ACMS Interconnection and System Architecture

3.2 ACMS Standard Functions

The main purpose of the DMU is to generate reports under certain conditions and at special events. The following tasks and reports are defined and certified by Airbus Industrie:

*** aircraft performance monitoring**
- A/C Performance Report, collects averaged engine and aircraft parameters acquired under stable conditions during flight phase cruise for aircraft performance analysis

*** engine trend monitoring**
- Engine Cruise Report, collects averaged engine parameters acquired under stable conditions during cruise
- Engine Take Off Report, collects engine parameters during take off when exhaust gas temperatures have reached the maximum
- Engine Trim Balance Report, collects engine vibration data at 5 different engine speeds
- Engine Run Up Report, collects parameters during engine run up phase

*** engine exceedance monitoring**
- Engine Gas Path Advisory Report, collects engine parameters at exceedance of gas path data as e.g. temperatures or rotations
- Engine Mechanical Advisory Report, collects engine parameters at exceedance of engine mechanical data as e.g. oil pressure or vibrations.
- Engine Divergence Report, collects parameters in case of divergence of exhaust gas temperature or nacelle temperature during symmetrical engine loads
- Engine Start Report, collects parameters during engine start phase in case of exceedance of parameters or aborted engine start

*** APU health monitoring**
- APU Main Engine Start/Idle Report, collects parameters during APU start and during the APU starts the engines
- APU Shutdown Report, collects parameters at APU shutdown due to APU failures or exceedance conditions

*** miscellaneous functions**
- Load Report, collects parameters at hard landing or at exceedance of inflight loads
- Environmental Control System Report, collects aircondition and pressure parameters in case of exceedance of those parameters
- Ram Air Turbine Test Report, collects parameters during ground test of the Ram Air Turbine
- free programmable reports, collects user selected parameters for special investigations

3.3 Data Recording

The A330/340 ACMS provides data recording functions as follows:

- Digital ACMS Recorder (DAR):
Continuous recording of flight data on magnetic tape, controlled by trigger logic. The DMU allows selection of the recording speed either 64, 128 or 256 words per second. Each word consists of 12 bits, the parameters which shall be recorded and the bits can be selected of the input parameters. Recording can be controlled by a total of 96 programmable start/stop trigger conditions. 120 seconds of history buffer are provided, to allow pre-event recording.
The conventional magnetic tape cassette recorder can be substituted by an optical disk recorder which provides 128 Mbyte disk capacity.

- The integrated Smart ACMS Recorder (SAR): It provides 4 Mbyte capacity arranged in 8 independent recording channels. Each channel can be used to record up to 127 parameters up to 10 bits. Up to 32 start/stop trigger conditions can be defined for each SAR channel. A 5 minutes history buffer can be programmed to enable pre event recording. The SAR data are stored in a compressed form retrieved by floppy disk and are decompressed and presented on ground on a PC.

3.4 Operator/ Ground Interface

The DMU provides interfaces for operator dialogue, ground communication and input/output of data. ACMS reports can be either printed on the cockpit printer, or transmitted to ground via ACARS or retrieved by floppy disk via the cockpit disk drive unit (MDDU). The components of the operator/ ground interface of the ACMS are presented below. Figure 2 gives an overall view about the available communication channels and the operating environment.

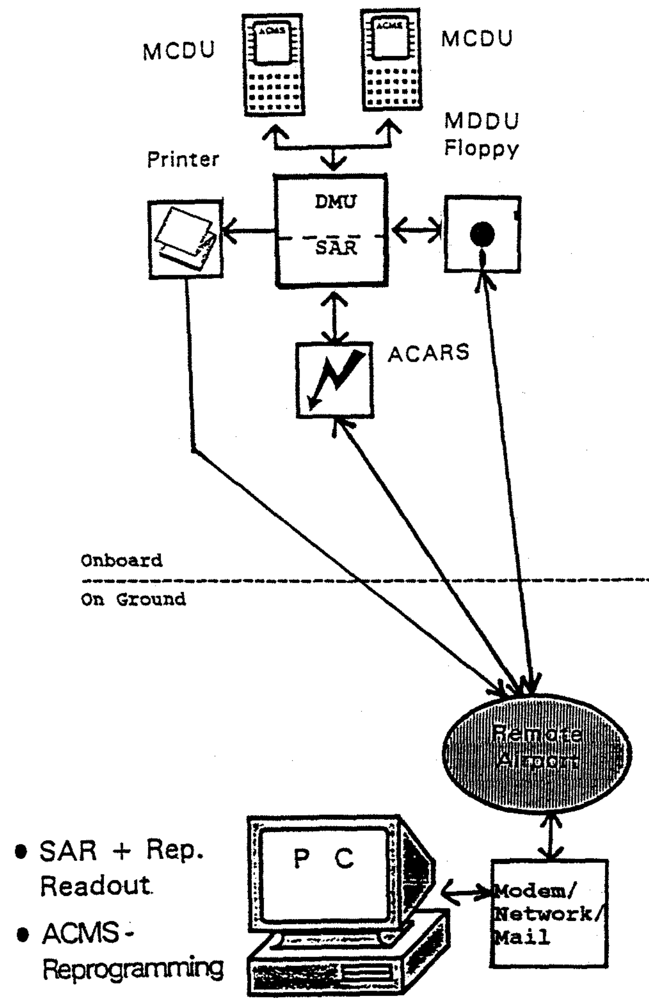

Figure 2: ACMS Operating Environment

The components shown on figure 2 are described as follows

MCDU: Multipurpose Control an Display Unit (according to ARINC 739):
The MCDU is a combination of an alphanumeric keyboard with a colour display with a text display of 24 characters in 14 lines.

ACMS usage:
- selection and online display of aircraft parameter values
- selection of reports to be generated
- control of DAR and SAR recording
- display of list of stored reports and SAR files
- miscellaneous control and reprogramming menus

Printer: Multipurpose Printer (ARINC 744)

An A4 sized thermo printer located in the cockpit.

ACMS usage:
- print out of ACMS reports
- print out of MCDU screens
- print out of software dump and load messages

ACARS: Aircraft Communication Addressing and Reporting System (ARINC 724B)
The ACARS provides an aircraft/ground communication link during flight. The messages can be transmitted either via VHF or SATCOM.

ACMS usage:
- downlink of reports
- uplink of requests for report generation
- upload of new DMU software (optional)

MDDU: Multipurpose Disk Drive Unit (ARINC 615)
The MDDU is a disk drive unit for 3.5" high density floppy disks with 1.44 Mbyte capacity.

ACMS usage:
- dump of reports and SAR files
- upload of new DMU software

DAR: Digital ACMS Recorder (ARINC 591), directly connected to the DMU, not shown on figure 2:
A magnetical tape cassette recorder or an optical disk recorder can be used.

ACMS usage:
- recording of user defined parameters
- storing of reports

3.5 Programming Capability and Flexibility

Ground Software Equipment (GSE) which runs on a PC assists the user in programming the DMU. The programming is performed menu guided. When the programming session is finished, a setup database is generated. This setup is stored on a floppy disk and loaded by the MDDU into the DMU. This means in case of software change the DMU needs not be removed from the aircraft.

The DMU software is split into two parts:
- the system software, which comprises the complete operational DMU software including all Airbus Industrie defined standard functions.
- the setup database, which comprises all items programmable by the customer.

The menu driven and graphically supported GSE software allows definition of programming items as follows:
- selection of output rules, i.e. to select the output devices for each report and the flight phase when the output shall be performed
- modification of standard trigger conditions
- addition of trigger conditions
- creation of complete new reports (layout, parameters and trigger conditions)
- programming of the DAR (parameters and start/stop conditions)
- programming of the SAR (parameters and start/stop conditions)

3.6 Readout Software

A second software package which runs on the same type of PC as the reconfiguration software is used for read out and presentation of the data generated by the DMU after having been retrieved via floppy disk. Functions as follows are available:
- display and print out of reports
- decompression of SAR files and graphical presentation of SAR data

4. Applications

4.1 Example: Aircraft Performance Report

An example for the A330/340 ACMS expanded capability and flexibility is demonstrated by the new concept for the A/c Performance Report:

This report is generated during flight phase cruise while the a/c is flying under stable conditions. This means that the DMU compares a set of "stable parameters" values with a given tolerance during 5 subperiods of 20 seconds each. The set of "stable parameters" comprises e.g N1, N2, VACC, EGT, FF (refer to table 1) and so on. In case that the parameter values do not deviate more than the predefined tolerance, then the appropriate window is considered "stable". In case that 5 consecutive 20 seconds windows are found stable, then stable conditions are considered and an A/c Performance Report is generated. The DMU uses the gliding window technic, i.e. the 5 preceding windows are taken into consideration in summary, but in case that stable frame criteria is met for each subperiod but not over all 5 subperiods, then not all subperiods but only the first subperiod shall be discarded. In figure 3 the 4th subperiod does not meet stable frame criteria when compared with the 1st, but subperiod 2 to 6 meet stable criteria, and so the report is generated with parameters from subperiods 2 to 6.

Once a frame was found stable and a report is generated, the DMU calculates a "stable frame quality number" as follows:

The summary **VAR(A)** of all variances of stable frame parameter **A** over the entire stable frame (i.e. 100 seconds) is calculated and divided by the tolerance **TOL(A)** of that value.
The result is multiplied with a weighing factor **W(A)** , i.e.

$$W(A)*\frac{VAR(A)}{TOL(A)}$$

The above mentioned calculation is performed for each parameter. The weighing factors are adjusted with respect to their influence of the specific range of the a/c. Table 1 gives an overview about the influence of the stable frame parameters on the specific range.

The variations divided by the tolerance multiplied with the weighing factors for each individual parameter A, B, ...n are summarized and the result is the Quality Number (QA):

$$QA= W(A)*\frac{VAR(A)}{TOL(A)} + W(B)*\frac{VAR(B)}{TOL(B)} + ...$$

$$...+ \quad W(n)*\frac{VAR(n)}{TOL(n)}$$

The entire flight leg is divided in "searching times" and waiting times" and once a report is generated and the quality number is calculated, the DMU continues searching for stable periods during the actual searching time, see figure 4. The DMU calculates the quality number during each detected stable frame and compares it with the previous numbers. The DMU stores the report with the "best" quality number and prints it after flight or transmits it to ground via ACARS.

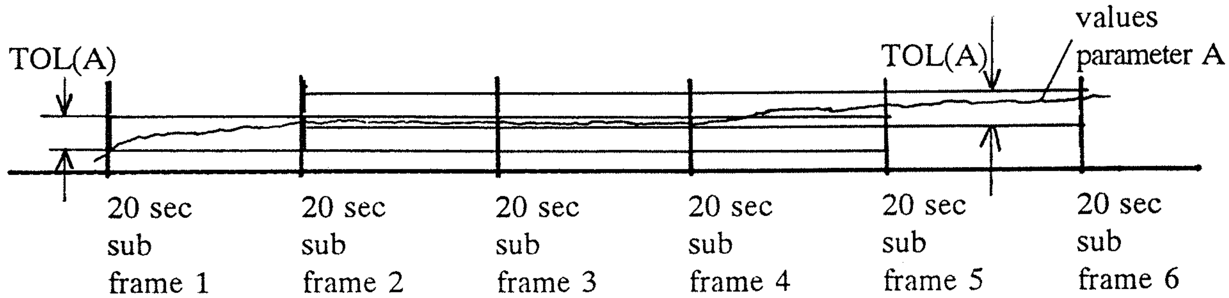

Figure 3: Gliding Window Technic

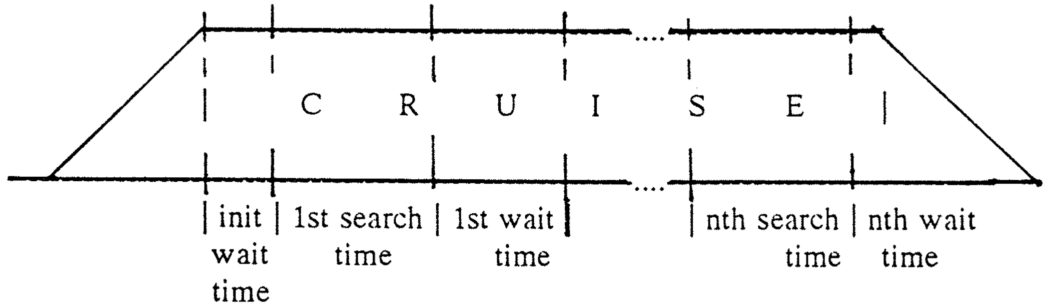

Figure 4: Searching and Waiting Times for Stable Frame Detection

Items as follows are flexible and can be reconfigured by ground software:

- all above mentioned stable tolerances
- all above mentioned weighing factors
- stable frame parameters itself
- parameter averaging times
- number of subperiods for stable criteria
- initial waiting time
- searching times
- waiting times between searching times
- number of flight legs between next report generation
- maximum number of reports per flight leg
- output rule, i.e. to be printed, dumped on diskette, transmitted by ACARS, after report generation

stable frame parameter	defined stable frame tolerance	effect on specific range (%) = weighing factor
Vertical Accelerat.	0.02 g	1.9
Ground Speed	2 knots	0.2
Altitude	30 feet	0.1
Mach Number	0.006	0.3
Total Air Temp.	0.5 deg C	0.03
N1 Rotation	2 %	5
N2 Rotation	1 %	7
Fuel Flow	100 Kg/hour	6
Exhaust Gas Temp.	20 deg C	5

Table 1: Stable Frame Parameters Influence on Specific Range (Preliminary Values, not yet adjusted finally)

4.2 Procedure for Running a Trouble Shooting Task

The following principle example shows how a special investigation of a problem can be performed within a short time without any need to enter the aircraft (refer to figure 2):

1. Step: Start the reconfiguration software on the PC on ground and select parameters which shall be investigated for free programmable report.
2. Step: Select for presentation of parameter values
- history time, i.e. pre event time which shall be comprehended for parameter investigation,
- averaging time, in case that the parameter values shall be averaged over a time interval,
- interval time, in case that parameters shall appear in the report in time intervals.
3. Step: Define trigger logic for generation of the report.
4. Step: Define output rule, e.g.:
- "transmit via ACARS as soon as generated" and "1st try VHF, 2nd try SATCOM in case that VHF has no connection to ground",

and/or
- "dump online on diskette"

and/or
- "print at end of flight"

5. Step: Send new setup via ACARS to DMU.

The DMU then automatically generates the report as soon as the trigger logic becomes true and then e.g. transmits it by ACARS to ground via VHF or via SATCOM, depending on what is available.

6. Step: Use ground PC for read out of the report.

5. Conclusion

Flexible and efficient aircraft condition monitoring is introduced now with the advanced ACMS for the Airbus A330/340. An efficient ground tool with its enhanced programming capabilities allows any airline user to adapt the system to the specific operating environment and increases the versatility of the DMU as a trouble shooting tool for any type of investigations.

List of Abbreviations

A/c	- Aircraft
ACARS	- Aircraft Communications Addressing and Reporting System
ACMS	- Aircraft Condition Monitoring System
ADIRU	- Air Data and Inertial Reference Unit
AI	- Airbus Industrie
APU	- Auxiliary Power Unit
ARINC	- Airlines Electronic Engineering Committee
BMC	- Bleed Monitoring Computer
CMC	- Centralized Maintenance Computer
CPC	- Cabin Pressure Controller
DAR	- Digital ACMS Recorder
DMC	- Display Management Computer
DMU	- Data Management Unit
ECB	- Electronic Control Box (APU)
EGT	- Engine Exhaust Gas Temperature
EIVMU	- Engine Interface and Vibration Monitoring Unit
FCDC	- Flight Control Data Computer
FCU	- Flight Control Unit
FDIU	- Flight Data Interface Unit
FF	- Fuel Flow
FMGEC	- Flight Management, Guidance and Envelope Computer
FCMC	- Fuel Control and Management Computer
FWC	- Flight Warning Computer
GPWC	- Ground Proximity Warning Computer
GSE	- Ground Support Equipment
LGCIU	- Landing Gear Control and Interface Unit
MCDU	- Multi-purpose Control & Display Unit
MDDU	- Multi-purpose Disk Drive Unit
N1	- Engine N1 Rotation
N2	- Engine N2 Rotation
PC	- Personal Computer
PRTR	- Cockpit Printer
QAR	- Quick Access Recorder
SAR	- Smart ACMS Recorder
SATCOM	- Satellite Communication
SDAC	- System Data Acquisition Concentrator
SFCC	- Slat Flap Control Computer
VACC	- Vertical Acceleration
VHF	- Very High Frequency
WBC	- Weight and Balance Computer
Zone CTL	- Zone Controller