THE FLIGHT MANAGEMENT SYSTEM WITHIN WORLD-WIDE COMMUNICATION/NAVIGATION/SURVEILLANCE AND AIR TRAFFIC MANAGEMENT APPLICATIONS

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Abstract

This report presents the results of the study project "Advanced Flight Management System (AFMS)", partly funded by the Directorate General DGXII of the European Commission within the APAS programme. In the course of the project functional requirements for an Advanced Flight Management System were collected and possible concepts were proposed for the realisation of the new crew interface, the integration of the AFMS in the future Air Traffic Management environment and the integration with other onboard systems. On this basis ongoing research and development efforts to bring forward the state of the development of an AFMS in Europe were identified.

1. Introduction

The Flight Management System (FMS) of today has introduced operational advantages and significant cost savings through offering the possibility of an automatic, fuel efficient flight from take-off to landing. However, the FMS with its high level of automation has dramatically changed the pilot's role, and in some cases for the worse. These problems will be even more severe with the introduction of 4D-navigation and other requirements of the future Air Traffic Management (ATM) environment. The FMS will become the focal point of the future onboard systems to support advanced world-wide Communication/Navigation/Surveillance (CNS) and ATM applications and will therefore dominate cockpit avionics.

This paper presents the results of the study project "Advanced Flight Management System (AFMS)" which was tasked and partly funded by the Directorate General DGXII of the European Commission within the APAS Programme (Contract-No. AERA-CT94-0001). The project was co-ordinated by Daimler-Benz Aerospace NFS (DASA-NFS) with GEC Marconi Avionics (GMAV), Dassault Electronique (D.E.), the Defence Research Agency (DRA), the Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR), Eurocopter Deutschland (ECD) and Dornier Luftfahrt (DOLF) as further team members. The duration of the project was from December 1994 until October 1995. The study project was performed in order to define research and development efforts which will bring forward the state of the development of an AFMS in Europe. The study was mainly focused on human factors issues on the flight deck and their relationship to ATM. Therefore, in the course of the described project functional requirements for an AFMS were collected and possible concepts were proposed for the realisation of the new crew interface, the integration of the AFMS in the future ATM environment and the integration with other onboard systems. Necessary research and development efforts for the future were identified on this basis. During the project fixed-wing as well as rotary-wing aircraft aspects were covered.

2. Project Overview

The AFMS study project was structured into 12 work packages as shown in figure 2.1. In work packages 1.1, 1.2 and 1.3 the requirements for an AFMS were assessed from different points of view providing the basis for the definition of AFMS functions in work package 1.4. Parallel to the functional requirements analysis, the available experience with present FMS pilot interfaces (work package 2.1) and the computer-human interface (CHI) concepts of pertinent research efforts were evaluated (work package 2.2). The outcome, together with the results of the definition of the AFMS functions (work package 1.4) served as an input to work package 2.3, defining the preliminary AFMS crew interface concept. This definition was followed by an identification of human-AFMS interface risks (work package 2.4). Parallel to the CHI activities, the integration with regard to the future ATM (work package 3.1) and with regard to onboard systems (work package 3.2) was assessed. The results of all work packages provided the basis for the identification of necessary research and technology development (RTD) efforts in work package 4.

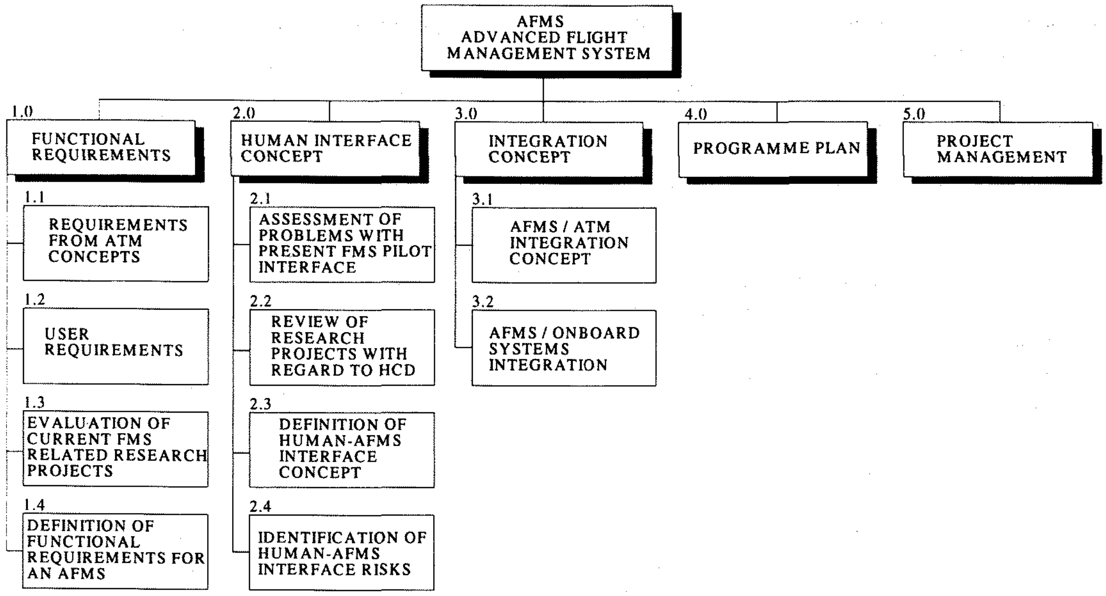

Figure 2.1: Work Breakdown Structure

During the whole project a project management task was performed (work package 5). An overview of the results is given in the following chapters.

3. Project Results

3.1 Overview

In this section a summary of the main results achieved in the course of the project is given. This presentation concentrates on the following areas:

- functional requirements for an AFMS
- crew interface
- integration of the AFMS in the ATM environment
- integration of the AFMS with other onboard systems
- research and technology development efforts

3.2 Functional requirements for an AFMS

The Advanced Flight Management System shall provide basic capabilities to meet the ATM objectives. For that reason, an intensive review of existing ATM concepts was performed. Operational requirements for an AFMS were derived from the ICAO CNS/ATM concept for Future Air Navigation Systems (FANS) [2], the European Air Traffic Management System (EATMS) concept [5] and the concepts for the Airports/Air Traffic System Interface (APATSI) and the Surface Movement Guidance & Control System (SMGCS).

Further, two European research programmes have been evaluated in detail, and their content related to the FMS requirements to support advanced CNS/ATM applications as specified by a FMS Task Force made up of Airlines, Industry and Government agencies [1]. Also taken into account in the evaluation were the research programmes being undertaken for the FAA in the USA [4]. The European programmes evaluated in detail were, firstly, the Experimental Flight Management System (EFMS) project, which is part of the Eurocontrol PHARE (Programme for Harmonised ATM Research in Eurocontrol) programme, and secondly, the FANSTIC (Future ATM, New Systems and Technologies Integration in Cockpits) programme funded by the European Commission.

The establishment of the user requirements of an AFMS for fixed-wing aircraft was realised by use of extensive inquiries among aircraft operators and pilots. For that purpose, a questionnaire was designed aimed at comprising all important aspects with regard to flight management functions in the future ATM environment [8]. The user requirements collected by use of the questionnaire and interviews were in full congruence with the desired modifications resulting from the evaluation of flight trials with a Honeywell FMS onboard the Dornier 328 aircraft. Those requirements are also valid considering helicopters as long as they operate in the future ATM environment for commercial passenger transport. Additional requirements occur when the specific helicopter operations and missions are taken into account (such as medical service, aerial work, ...).

Any conflict of requirements occurring between the various sources - current FMS requirements, future user and ATM concept requirements and any pertinent requirements generated from ongoing relevant study programmes - was finally identified and resolved to form a coherent definitive set of AFMS requirements, which shall be used as a baseline for future work. This consolidation of the FMS requirements was realised by use of a workshop on FMS user requirements, held in April 1995 at the Lufthansa Flight Operation Centre at Munich Airport. At this workshop the requirements already collected were presented by the study team and discussed and consolidated with pilots and engineers from Deutsche Lufthansa, British Airways, Air Inter, Dornier Luftfahrt and Fokker Aircraft.

During the discussions it was made clear that the implementation of the requirements will be time, region and application dependent. The development and the full deployment of AFMS will be a complex process since it will be applied world-wide and requires the combination of several major elements, such as onboard aircraft equipment, telecommunication network and new capacities for Airline Operation Control Centre's (AOCC) and ATM, to be available simultaneously. Operational requirements from the ATM concepts have to be considered, such as Controller/Pilot Data Link Communication, Automated Air/Ground Data Interchange, 4D navigation, Automatic Dependent Surveillance (ADS), 4D planning & trajectory negotiation functionality, improved airborne collision avoidance and taxi guidance. A proper distribution of functions between human and machine is of high importance when considering the new functions to be added. Especially the change from voice towards data link communication enables a higher degree of information automation. It is essential to keep the aircrew "in the loop". The aircrew must actively approve all data entry into the subsystems of the aircraft. The development of appropriate human/machine interfaces to ease use of the FMS is of crucial importance. With the comprehensive facilities required in an advanced FMS, there remains a significant task to provide the pilot with the data inputting and information display facilities that are essential to ensure satisfactory aircraft operation with crew workload close to the optimum.

To sum up the results in short the following main requirements for an AFMS for fixed-wing and rotary-wing aircraft were identified:

- processing of the following messages (via data link from ATC, AOCC or other aircraft):
    - flight path (string of waypoints with attributes)
    - flight path clearances
    - alternative flight paths (string of waypoints)
    - surveillance squitter from other aircraft
    - meteorological data
    - short time restrictions
    - initialisation, performance messages
    - free text messages
- generation of the following downlink messages (via data link to ATC, AOCC):
    - present data (string of waypoints, present position, next waypoint, next+1 waypoint + attributes) for ADS
    - flight plan change requests (string of waypoints)
    - weather information requests
    - slot and gate information requests
    - maintenance reports
    - automatic transmission of wind/temperature
- crew interface:
    - use of the navigation display and an enhanced Control Display Unit (CDU)
    - careful use of speech output (not as general communication medium)
    - use of a cursor-device to modify the actual flight plan on the navigation display
    - input of further crew information into the AFMS using a keyboard and a cursor-device with a graphical user guidance on the enhanced CDU
    - eventually combination of the user guidance with speech input
    - fault-tolerant data entry formats
    - avoidance of different ways for inputs
    - attention getting for incoming data link messages
    - activation of an uplinked or alternative flight plan with "execute"-function
    - no necessary acceptance of information messages
    - storage of uplink messages and display/print on request
    - presentation of the lateral flight plan (flight legs, radio symbols, flight plan values, ...)
    - presentation of the vertical flight profile (visualising the intended flight path)
    - presentation of uplinked/alternative flight plans
    - presentation of a turn prediction (track during next 60 seconds)
    - weather overlay on request
    - traffic overlay on request
    - terrain (2D/3D) overlay on request
    - presentation of a taxi-chart on request (but no taxi guidance)
    - alphanumeric presentation of the flight plan
    - presentation of airport information on request
    - presentation of departure charts/approach charts on request
    - presentation of ATC uplink messages
    - presentation of alternates/emergency fields

- navigation/guidance/planning:
  - navigation on Global Navigation Satellite System (GNSS) and Differential GNSS (DGNSS) input
  - exact position detection without position shift
  - 4D guidance according to the actual flight plan (incl. holding patterns, curved approaches, ...)
  - non-precision approach capabilities
  - processing of uplinked and accepted trajectories and trajectory changes
  - transfer of crew inputs in alternative flight paths
  - advising of horizontal and vertical separation
  - planning of a 4D trajectory from present position to destination
  - planning of alternative 4D trajectories on crew request
  - comparison of alternative trajectories ("what if"-questions)
  - avoidance of discontinuities in the trajectory (planning of missing legs)
  - diversion route recommendations (because of weather conditions)
  - alternate and emergency field recommendations (because of engine failure)
  - special applications (e.g. pattern flying for search and rescue operations)

- performance:
  - calculation of performance limitations
  - calculation of time or fuel optimum for 4D-Navigation
  - calculation of Top of Climb/Top of Descent (TOC/TOD)
  - calculation of Estimated Time of Arrival (ETA)
  - take-off and landing performance calculations

- flight crew alerting:
  - flight crew alerting in case of a violation of the Minimum Safe Altitude (MSA)
  - flight crew alerting in case of a deviation from the cleared 4D trajectory
  - monitoring of the flight progress
  - monitoring of aircraft limitations
  - position shift monitoring
  - crew error detection as additional feature in the long future

- database:
  - terrain and MSA information in database
  - airport/heliport surface information in database
  - all approach procedures available in database
  - easy way for creating waypoints and adding them to the ones already stored
  - capability for on-line updates with regard to temporary revisions

3.3 Crew interface

As the basis for the preliminary concept definition for the crew interface the operational problems of present fixed-wing FMS pilot interface were assessed, to a significant degree realised by use of inquiries among airline pilots. Some interesting statements with regard to the influence of today's cockpit automation on flight guidance and to the resulting problems were collected. All the collected statements and items show the operation of the FMS by use of the CDU as the main disadvantage of the system, since too many functions are offered, insufficient user support is given and too many finger trouble problems are caused. These problems lead to a loss in the pilots situation awareness and his concentration on flight guidance especially in critical situations. Future systems should provide an easy operation mode in order to enable the use of all desired functions and to reach maximum assistance in flight guidance. These enquiry results were confirmed through the evaluation of accident and incident reports and through the evaluation of the Dornier 328 flight trials. The general statement of the Dornier 328 test pilots with regard to FMS functions was that they often do not make optimum use of the FMS capabilities because there are too many exotic features that are hardly ever used, making the really useful features too hard to find. Enquiries among helicopter pilots showed that the present FMSs are overloaded with functions offering a too big amount of information on the background of a comparatively high percentage of "head-up/eyes-out"-time needed for helicopter operation. With respect to crew interface aspects for helicopters future FMS pilot interface improvements must be aimed at reducing the overall system complexity and establishing a "comfortable dialogue", mission adaptive between pilot and FMS.

In parallel, the CHI design concepts of relevant research projects regarding Flight Management and Pilot Associate Systems were summarised and evaluated [7]. The summary of each project included a basic characterisation of system input/output capabilities as well as detailed structure of input/output hierarchies, detailed display layout and input device design.

Based on the definition of AFMS functional requirements and considering the CHI problem analysis and current design approaches, a preliminary functional dialogue between the crew and the AFMS was defined. Potential dialogue mediums for the interface between the crew and the AFMS were discussed, with the aim in defining the most appropriate dialogue means for the human-AFMS interface. The selection of suitable dialogue medium used a bottom-up approach to build up a specification of the human-AFMS interface. The devices were firstly reviewed by classifying them into output and input categories, where each category was assessed in terms of attributes, characteristics and performance. Each of these mediums were then related to their most suited field of application for the human-AFMS interface. The advantages and limitations of each of these devices was also considered to determine the medium's overall suitability. It was concluded that, given a suitable improvement in the technology, speech recognition and flat panel displays will be of significant benefit in cockpit communications. It was stated that the CDU page hierarchy is unacceptable and recommended that it should be remodelled to take into account the use of large screen displays in conjunction with some form of graphical interface. It was stated that the optimal crew workload will be obtained with a system where there is an overall, close, direct and natural match between the functions performed by the AFMS and their visual representations. This is not provided by the present FMS.

Given the interface requirements and the recommended dialogue medium, a preliminary identification of the human-AFMS interface concept was described. The definition looked at the implementation of the AFMS in the new CNS/ATM environment, and from it, determined a strategy for human-AFMS interaction. Five key procedures, in which the AFMS will be frequently used, were outlined (Request for Automatic Terminal Information Service (ATIS), Route negotiation, Avoiding a thunderstorm, Aircraft flying outside of the agreed route and Engine out). Each one was accompanied by example displays and envisaged steps involved in executing them.

In order to give example definitions of the human-AFMS interface scenarios, it was necessary to identify the likely devices to be used. Figure 3.1 and 3.2 show initial concept designs for the AFMS CDU and the AFMS mode of the navigation display. It should be noted these are only preliminary designs. Further refinement of these concepts must be carried out.

Figure 3.1 shows an example of an initial AFMS CDU concept. Compared to the current FMS CDU, it has an enlarged display area, more line selection buttons due to the larger screen area, multi-push buttons to reduce the number of keys required and a cursor control device in the form of a rollerball with selection button for implementation of a graphical user interface. The figure shows the CDU at the top level of this page structure. The display area contains soft key legends around the outer edge of the display area with the possibility to show, perhaps route information or other pertinent flight information in the middle of the display area. The Request soft key has been highlighted to denote that this is the option selected by the pilot, by either pressing the appropriate line selection button or by positioning the cursor over the required soft key and pressing the select button. After that action the Request page of the CDU is displayed and further selection can be made.

Figure 3.2 shows an example of an initial concept of the AFMS mode presented on the Navigation Display. The soft keys on the left hand side of the display are intended to be the modification methods that can be applied to the route.

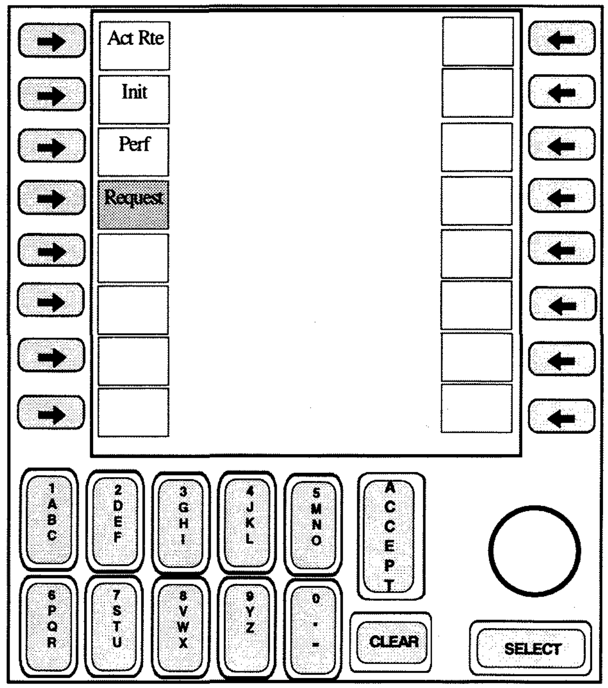

Figure 3.1 - Example CDU Layout

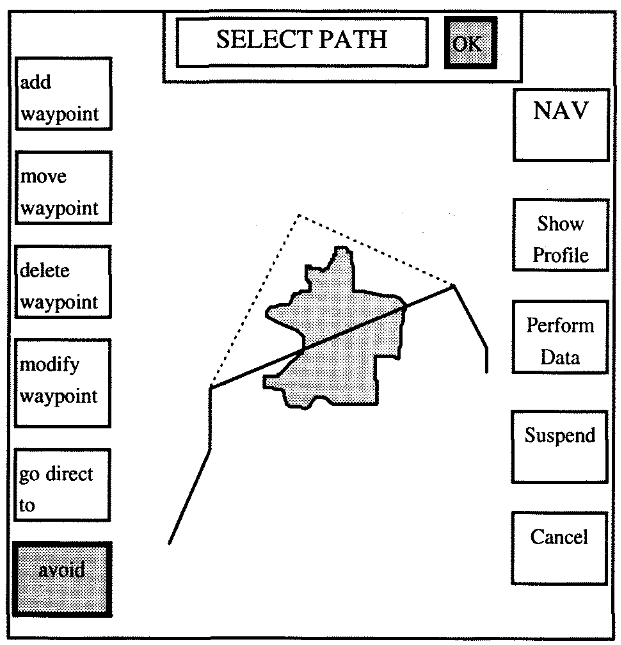

Figure 3.2 - Example Mode on Navigation Display

The bar at the top of the display is intended to be an information area. The NAV key is intended to allow the pilot to switch back to the standard navigation display, and The Show Profile key is expected to display the vertical profile of the route. The figure shows an example display of the selection of a new waypoint, taking the route around the thunderstorm. The Avoid soft key has been highlighted to represent its selection and will remain highlighted throughout this modification process to maintain pilot awareness of the mode of the AFMS. The dashed lines represent where the new route section would be if the waypoint was selected at that point. These dashed lines are expected to alter with the movement of the cursor so that the pilot can visually determine the best place for the new waypoint.

In general, two approaches to implementing CHI for the AFMS were identified:

- Minimising the use of CDU, by using the navigation display for graphical input/output and the CDU for textual input/output
- Enhancing the CDU to use it as the main, graphical input/output device for the AFMS

More detail of the intended aircraft implementation needs to be defined before a choice of implementation can be made. Both approaches are equally valid, although especially in the air transport sector the first approach is expected to gain in importance in the future. Further, both approaches are likely to be expanded by speech input as a third input device under the premise that this technology is evolving in the next years.

3.4 Integration of the AFMS in the ATM environment

An important part of the AFMS study project was to define the concept for integrating the airborne AFMS with the future ground ATM system, and to identify the potential risks associated with this AFMS/ATM Integration Concept. A number of studies and research programmes have been undertaken in Europe and in the USA to investigate potential improvements in airspace capacity and aircraft operating efficiency that might result from using a data link to provide closer integration between the ground and airborne elements of future ATM systems. The Air/Ground integration aspects of the following programmes have been reviewed in detail:

- the Eurocontrol PHARE programme, in particular within the Experimental Flight Management System (EFMS), Meteo, Data Link Study, and PHARE Demonstration programme areas
- The European Aeronautical Telecommunications Network (EURATN) project, funded by the Commission of European Communities (DG VII) [6]
- an FAA programme called the Flight Management System-Air Traffic Management Next Generation (FANG) project [4]
- a concept called "Free Flight" being defined by a Select Committee of the RTCA [3]

Based on the information obtained from the programme reviews mentioned above an AFMS/ATM Integration Concept could be defined. A long-term integration concept has been defined for the period 2010-2020, with suggestions for two evolutionary steps from today's system, covering the period up to 2000, and then from 2000-2010. The long-term concept, described below, involves free flight operations in autonomous airspace for low/medium traffic density situations, and negotiated 4D contracts in controlled airspace for all high traffic density situations. The overall operational strategy will ensure that the best equipped aircraft receive the best service (i.e. get minimum disturbance from their ideal flight path).

ATM system operation within the long-term concept will involve the type of airspace, and the associated airspace boundaries, being designated dynamically (i.e. designated according to the actual traffic demand for the relevant period of time). Direct routing will be used for all en-route flying (no fixed route structure). Two types of airspace will be available:

- Autonomous Airspace:
  - only used in low/medium traffic density situations
  - only available to suitably equipped aircraft
  - ground ATM system ensures that traffic density does not exceed a safe level
  - aircraft follow free flight trajectories
  - conflict detection and resolution using on-board system (Super Traffic Alert and Collision Avoidance System (Super TCAS))
  - independent safety back-up for collision avoidance provided by TCAS
  - all trajectories and modifications downlinked to the ground ATM system to enable overall system monitoring
- Controlled Airspace:
  - will apply to all high traffic density situations
  - ground ATM system ensures that traffic density does not exceed a safe level
  - ground ATM system responsible for conflict detection, resolution, system monitoring
  - conflict resolution instructions uplinked to relevant aircraft (resolution responsibility can be delegated to aircraft equipped for autonomous operation)
  - majority of aircraft operating to 4D contracts negotiated over data link

- less well-equipped aircraft given strategic instructions over data link
- tactical control by R/T will only be used in failure/emergency situations
- operational strategy ensures that best equipped aircraft receive the best service (i.e. get minimum disturbance from their ideal flight path)

This situation requires an AFMS with the following capabilities:

- 4D trajectory generation, taking into account pilot/ AOCC requirements, airspace restrictions, any ground ATM imposed constraints, and also any conflict resolution requirements (for autonomous operation)
- 4D guidance within bubble of airspace allocated by ground ATM system, or along ideal trajectory in Autonomous airspace
- contract negotiation with ground ATM system over data link (ATN)
- performance monitoring relative to Required Navigation Performance (RNP) for current airspace
- Precision Position Determination - using GNSS (high-integrity civil system)
- ATN Data Link using Satellite, VHF and Mode S links to provide two-way link between:
    - Pilot/Controller - for contract negotiation, strategic instructions, meteo forecasts
    - Aircraft/ATM system - for ADS etc. (no direct controller/pilot involvement)
    - Aircraft/AOCC - for airline operational, maintenance etc. purposes
    - Aircraft/Aircraft - fôr autonomous conflict detection and resolution
- Conflict Detection and Resolution - a Super TCAS providing medium-term (5-10 minutes) capability in autonomous airspace
- Collision Avoidance - TCAS to provide an independent short-term safety backup
- Cockpit Human-Machine Interface - displays and inputting capabilities to ensure adequate crew monitoring and control of FMS, Data Link, etc. in a 4D negotiated contract environment, and suitable traffic information displays for operation in autonomous airspace

The following ground requirements can be listed:

- Flow management system for all airspace, to ensure that traffic density does not exceed a safe level, and does not exceed runway capacities in Terminal Manoeuvring Area (TMA)
- Traffic monitoring using Radar and ADS with short-term (< 5 minutes) automatic conflict alert, tactical intervention if necessary using voice R/T link
- Long-term (20-30 minutes) conflict detection and resolution using computer aiding for the ATC Controller
- Trajectory prediction using downlinked aircraft parameters
- Negotiation to provide conflict-free bubble around agreed aircraft trajectory
- ATN Data Link using Satellite, VHF and Mode S links to provide two-way link between:
    - Controller/Pilot - for contract negotiation, strategic instructions, meteo forecasts
    - ATM/Aircraft - for ADS etc. (no direct controller/pilot involvement).
    - ATM/AOCC - ground link to provide a fully integrated planning/flow control/airline operational control system
    - AOCC/Aircraft - for airline operational, maintenance etc. purposes
    - Gate-link - used by ATM and AOCC when aircraft is on the stand
- Accurate short-term Meteo Forecasts - updated by actual meteo downlinked from aircraft

The potential risks identified with this proposed Integration Concept are mainly concerned with the conception and functionality of the ATM ground systems and the data link connection. The future AFMS will probably need to cope with different ATM systems and different levels of functionality. AFMS realisation could either provide limited functionality with regard to data link connection to the ground system, and provide communication management software to enable easy updating of the functionality, or it could attempt to cover all foreseen requirements at the risk of some parts of the functionality never being used. A compromise has to be found between these two alternatives in order to minimise the integration risks and the updating efforts. Therefore a continuous and intensive monitoring of ground system development is essential.

3.5 Integration of the AFMS with other onboard systems

The term «Integration» can be understood in two ways:

- Installation considerations, as a whole, that arise when implementing the AFMS functionality onboard existing or new aircraft
- Use of technology breakthrough, to gather new HW and SW implied elements or merge them with other related existing elements in order to get weight, volume and global costs savings

Both approaches have been considered in this project through an identification of the new functionality to be installed, the interfacing compatibility constraints and relevant standards to comply with, a review of the different design drivers and a review of advanced architectures trends and integrated avionics (in particular Integrated Modular Avionics (IMA)) with discussion of potential benefits.

Significant different approaches may exist in the way of associating the functions and hardware units. Therefore different functional allocation within Flight Management Systems may exist. The major functions which will be usually required for a FMS are (additional functions may be envisaged):

- En route navigation (2D and 3D)
- Terminal area navigation
- Flight guidance control
- Autothrottle control
- Flight plan negotiation
- Flight plan generation or modification
- Non precision approaches
- Airport taxiing
- Performances (speed, fuel) computations
- Flight crew interfaces

The AFMS has to provide crew interfaces, datalink interfaces and onboard sensor interfaces. The following considerations must be taken into account with regard to system interfaces:

- Interfaces have to be standardised to make sure that data communication between different units is guaranteed. FMS design shall provide for standardised data interfaces primarily based on data buses, and mostly ARINC buses (429, 629 or 646, 659?). Use of high speed buses such as Ethernet (646) is well encouraged. In smaller or older aircraft customised data busses or interfaces have nevertheless to be envisaged.
- The communication system between FMS and ATN will require the use of several standardised communication layer protocols.
- GNSS has to replace current position sensors with minimal architectural changes.
- FMS design must provide for displaying significantly more information to the aircrew and enabling an optimum configuration of displays for different stages of the mission, together with ensuring that the display formats used provide the data in an unambiguous, easily assimilable form.

Design drivers for AFMS functional architecture design are of several types and often interrelated in such a way that they present opposite interests. FMS design must take into account all pertinent and applicable recommendations and standards from organisations like AEEC, RTCA, EUROCAE, IATA, SAE, in terms of system architecture, interfaces (I/O signals and protocols) and hardware and software characteristics. Great consideration must be given to standards such as DO-178B, DO-160C, ARINC 702A and associated, ARINC 651 and associated, to ARINC project papers 660, 656, 756 and to foregoing activities such as those of the RTCA SC-182, and ARP 4754 (issued by SAE and EUROCAE WG-42). Future considerations must be to ensure that any standards enforced are universally accepted by all current users and all foreseeable users.

FMS design has to take into account the safety level to which the system has to fulfil for the intended aircraft. The safety level of an aircraft system could be achieved by the installation of redundant systems and additionally by installation of highly accurate failure monitoring software algorithm as required to fulfil the safety requirements. Hardware and software must take into account during development and certification phases RTCA-178 B (addressing software development in accordance with the required criticality level) and RTCA-160 C (system functional environment testing). Depending upon the implementation of safety critical functions within the AFMS, the appropriate provisions (HW/SW) have to be made in order to meet safety standards. Safety critical functions (e.g. landing operations) must be kept out of the AFMS. Implementing the classic FMS redundancy philosophy is to be considered in future AFMS applications. A safe and redundant system is therefore recommended for achieving its certification capability.

One of the most important driver for new generation FMS is that its design must provide for growth potential and easy integration of future evolution in order to provide for functional improvement and adaptation according to ATM development which will be progressively developed and implemented step by step in the next 15 years (or more!). Growth potential has to be provided by a highly modular approach as it is likely that implementation of all CNS/ATM functions will not be installed from the beginning. Open System Architectures and growth capabilities will be necessary, in order to support the different configuration grades with minimum installation impact.

Therefore, functional partitioning and hardware partitioning are highly required. For that reason, the concepts currently in development within the Avionics Computer Resources (ACR) working groups have to be carefully considered. Furthermore, IMA concepts may also be envisaged, but this is not a definite requirement. The availability of high capacity integration platforms will offer more flexibility in sharing common resources (RF receivers, data link ports, mass memories for data bases, computing power, interfaces with displays...) and will decrease significantly the global amount of wiring between units.

Several types of typical architectures are currently emerging depending on the intended application on new aircraft and existing aircraft already equipped with FMS or not. Besides a new FMS definition, new concepts are also emerging such as the GNSS Navigation and Landing Unit (GNLU) which will perform some FMS functions. Implementation issues need to be evaluated in considering both FMS related retrofits and new aircraft. FMS related retrofit programmes can go some way to incorporating the new technology and techniques into current aircraft but the new operational philosophies need to be included in the design of future aircraft for achieving the full benefits.

Current FMS installation architectures are mainly specific to each aircraft implementation and dependent from the usage (business or commercial), the crew number, the size and age of the aircraft due to the fact that each system can have different required functions, safety levels or numbers and types of sensors supplying the FMS with data. For smaller commuter aircraft, the installed avionics system must be low in weight and cost. Therefore many avionics suppliers offer a complete system which includes NAV sensors, EFIS, EICAS, FGS, FMS and others. Similarly today, almost every helicopter type presently in use has its unique system architecture and cockpit design with its specific allocation of functionality, which even holds true for different models of a single manufacturer. Various configuration versions per helicopter model due to multiple, diverging mission requirements form an extremely inhomogeneous landscape of helicopter system architecture.

Thus, integrating a flight management system has to be done on an individual baseline while privileging flexible system architectures applicable to a range of helicopter models and adaptable to all missions. As implementation of CNS/ATM will impact significantly on present onboard architectures, future Airborne Flight Management Systems will progressively consist of highly integrated systems with complex functions for aircraft navigation and performance management. So, high consideration must be given to integration of as many functions as possible (thus minimising the size of equipment), and to minimising the complexity of the system in order to simplify the certification processes. Depending upon requirements such as price target, space provisions, etc., an ideal compromise has to be identified which may be different from aircraft to aircraft.

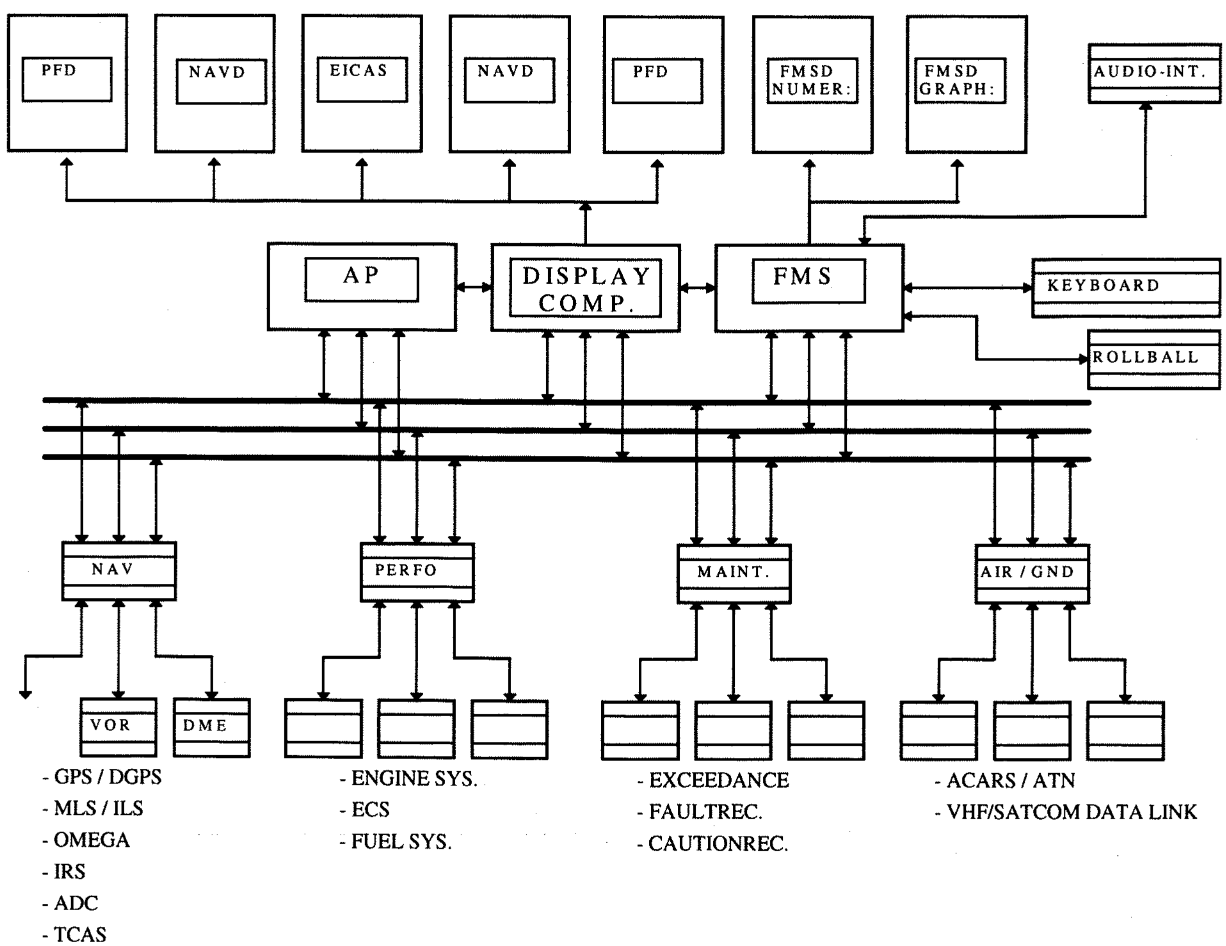

Figure 3.3: Data interaction architecture

Associated on-board systems must also be improved by performing their own data processing, and supplying the AFMS with important and pre-processed data only.This will reduce time consuming processes within the AFMS to allow additional data handling time for future features. A possible conceptional layout of such a data interaction architecture is shown in figure 3.3.

Future Flight Management Systems will be a central component of an integrated approach to Air Traffic Management and will form the heart of the aircraft's avionics. As significant changes will occur in the ATM environment, more functions will be required with the next generation FMS. As a consequence of the increased functionality, special attention has to be spent on integrity, redundancy, certifiability and safety requirements, growth potential and customisation, modularity and cost/benefits optimisation. A recommended solution is to approach the AFMS development with an evolutive design by the use of a modular segregated and partitioned software in order to provide for growth potential and minimising certification costs. This could be achieved with a generic processing platform with a well balanced implementation of IMA concepts.

3.6 Research and technology development efforts

Based on the results presented in the previous chapters research and technology development (RTD) programme plans to support the AFMS realisation in Europe for the next 10 years could by proposed. For that purpose, two RTD periods were identified which are described in the following.

The first period for future research and technology development is seen for the period from 1995 to 1999. The following main research areas for this time frame can be summed up:

- four-dimensional trajectory planning and guidance with special emphasis on optimised 4D flight plans and aircraft efficiency
- trajectory negotiation with ATM/AOCC via data link
- advanced crew interface:
    - use of a CDU with graphical user guidance
    - use of the EFIS for flight plan representation and manipulation
    - advanced information presentation (presentation of 3D/4D trajectories, free flight airspace situation, data link messages, ...)
    - advanced information access (page structure, menu layout, menu access, ...)
    - use of a cursor-control-device as input medium
- improved data link systems with regard to capacity, number of messages, response time, end-to-end checks, integrity, ...
- optimised avionics integration with emphasis on adequate functional software partitioning
- improved and revised certification processes

This time period fits in the 4th Framework programme of the European Commission. The described research areas were covered within the call for proposals of the different directorates. However, also other programmes than the 4th Framework are related to the described research topics for the next 5 years. As an example the PHARE programme should be named in which especially the data link and trajectory negotiation issues are addressed. Therefore, an intensive information exchange between the different projects is essential.

A possible second period for future research and technology development is estimated for the period from 2000 to 2005. As main research areas for this time frame the following topics are seen:

- extended trajectory negotiation with ATM/AOCC via data link under consideration of the updated operational ATM concepts (free flight concept)
- advanced crew interface:
    - use of a speech recognition system as third input device
    - integration of the speech input technique in the information input and access (page structure, menu layout, menu access, ...), in parallel to the cursor-control-device
- introduction of a situation interpretation capability of the system
- modelling of the crew behaviour
- crew error and intent recognition based on the flight situation and the crew model
- flight crew alerting or system adaptation dependent on recognised crew error or intent

This identification of research areas is intended to assist the preparation of the call for proposals for future programmes such as the 5th Framework programme of the European Commission. Special emphasis is to put on the extension and enhancement of the crew interface by use of the speech recognition and the introduction of an intelligent situation interpretation and crew error and intent recognition capability of the flight management system which then will move into the role of a cockpit assistant system. Further, the continuously changing ATM environment has to be considered and resulting changes with regard to the AFMS trajectory planning and negotiation capabilities have to be performed.

4. Future Activities

In the last chapters functional requirements for an AFMS as well as preliminary concepts for the crew interface, the AFMS/ATM integration and the AFMS/onboard system integration were presented. It was made clear that the role of the FMS will significantly change in the future ATM environment resulting in a high demand for new FMS concepts and technologies. Necessary research and technology development efforts have been identified and described.

For that reason, the core team of this study project continues their activities in the field of air traffic and flight management within the 4th Framework of the European Commission. Research topics such as four-dimensional trajectory planning, negotiation and guidance as well as the advanced crew interface are addressed in the DGXII Brite/EuRam project "Advanced Flight Management System (AFMS)" and in the DGXIII telematics application project "Airborne Air Traffic Management System (AATMS)". While the DGXII programme focuses on navigation and ATM onboard functions, the DGXIII programme is mainly related to the definition and validation of the corresponding CNS/ATM configuration. The optimised avionics integration and the adequate functional software partitioning is addressed in the DGXII Brite/EuRam project "Generic Avionics Scalable Computing Architecture (GASCA". Within all three mentioned projects a concentration is assured on the aforementioned necessary research and technology development efforts whose importance did become obvious in the course of this AFMS study project. Therefore, a concentration on the real needed efforts to support the AFMS realisation in Europe is guaranteed.

However, it should be pointed out that also other programmes than the 4th Framework are related to the described research topics for the next five years. As an example the PHARE programme should be named in which especially the data link and trajectory negotiation issues are addresses. Therefore, an intensive information exchange between the different projects is essential.

5. Conclusion

This paper presented the results of the study project "Advanced Flight Management System (AFMS)". The project was focused on human factors issues on the flight deck and their relationship to ATM. Functional requirements for an AFMS were identified and concepts for the crew interface, the AFMS/ATM integration and the AFMS/onboard integration were proposed.

In comparison to the FMS of today the AFMS has to fulfil the requirements of the future ATM environment with regard to Controller/Pilot Data Link Communication, Automated Air/Ground Data interchange, 4D navigation, 4D planning and trajectory negotiation functionality and improved airborne collision avoidance. The development of an appropriate crew interface to ease the use of the FMS is of crucial importance. According to the results of this study project the future crew interface shall use the CDU and the Navigation Display as input and output devices. The AFMS CDU should have an enlarged display area and a cursor control device for the implementation of graphical user guidance. Flight plan updates and changes should be possible also by use of the cursor on the Navigation Display.

The AFMS will be integrated in the future ATM environment involving free flight operations in autonomous airspace for low/medium traffic density situations and negotiated 4D contracts in controlled airspace for all high traffic density situations. The AFMS will be a central component of an integrated approach to ATM and will form the heart of the aircraft's avionics. As a consequence of the increased functionality, special attention has to be spent on integrity, redundancy, certifiability and safety requirements, growth potential and customisation, modularity and cost/benefits optimisation. The recommended solution is to use a modular AFMS design, with segregated and partitioned software, which will provide growth potential to meet the evolving ATM requirements, and also minimise certification costs. This could be achieved with a generic processing platform with a well balanced implementation of IMA concepts.

6. References

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