DIGITAL ENGINE CONTROL UNITS FOR AN
FIGHTER ENGINE AND AN AUXILIARY POWER UNIT
A COMPARISON

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Abstract

The technology of the engine controllers has been changed in the last decade from hydromechanical solutions via analogue-electronical to digital versions. This raised the question, whether it is possible to develop an universal controller for different types of engines instead of special solutions. Bodenseewerk is developing and producing digital engine controllers for different engine types. These controllers are special designs. Via a brief comparison reasons for the special design should be pointed out.

The comparison is divided into two major parts:
- the hardware concept
- the software concept.

First of all the different redundancy concepts of the controllers forces a different design. Nevertheless there is the possibility to use one lane of a redundant controller for a single lane design. But as shown in the paper there are in spite of a lot of commonalities too much differences (different number of inputs and outputs, data exchange to the redundant lane, more software etc) to design a cost-effective universal controller.

1. Introduction

Since engine controllers have been built in a digital manner very often one hears the question:
"why do you develop special controllers for different engine types and do not use the same as designed and produced for one type of an engine?"

What is the reason for such a question?

Each engine whether it is an auxiliary power unit (APU) or a fighter engine has rotating parts, measuring points for temperatures and pressures and it needs fuel flow /1/. Using a digital computer where one can implement different kinds of control laws, it should be very simple to use the same controller for different engines.

FIGURE 1.1 Fighter Aircraft with Engine and APU and their Controllers.

2. Overall Requirements for Engine Controllers

First of all, it has to be clear, that one can compare only similar technologies, i.e. the controllers for both types of engines must have military standard, for example.

Reading the specifications of the controller of an auxiliary power unit and
those for a fighter engine the following conclusion is obvious:

Independent of the type of the engine the design aims for the controllers are /3/:

- improvement of engine performance
- minimization of power dissipation
- reduction of volume and weight
- reduction of production costs
- high reliability
- easy maintainability

The controllers have to fulfill different tasks, which are partially very similar. The main important are /4/:

- start the engine
- accelerate the engine to IDLE
- control the engine as a function of one or more input parameters by variation of one or more output parameters
- minimize pilot workload during normal and abnormal operating conditions
- cut the engine off

Doing this the control behavior has to meet at least the following requirements:

- no permanent control deviation
- transient behavior of a second order system with a damping factor of about 0.8
- overshoot not greater than 0.5 of a given change of command input
- sampling rate about 20 msec
- delay time between input and output not greater than some 30% of the sampling rate.

Very often there are also some special requirements for the design. The most general of them is, that all components should have a special reliability standard. A very special requirement is e.g. the specification of the type of the microprocessor.

The controllers should have at least x-K-Byte memory for normal- and test operation and a special amount of non volatile memory to store failures during ground and flight operation and the pilot should be informed about the conditions of his engines.

The controllers should be protected against EMI, LEMP, NEMP etc., but nevertheless they should have minimum volume, weight and low costs /5/.

Last but not least the failure rate of the controllers and their associated sensors and actuators shall be better than a given value and the rate of failure leading to a hazardous operating condition shall be less than

1/1,000,000 engine hours.

Most of these overall requirements are very similar for the controllers of both engine types. But there are additionally a lot of special items. These different items reflect hardware as well as software.

The following chapters will discuss these in more detail and will outline whether it is possible to use the same kind of controller for both types of engines or not.

3. Hardware

3.1 System Concepts

The requirements and design aims, mentioned in section 2 will be obtained with the following key features independent of the type of controller:

- application of powerful 16 bit microprocessor of the latest generation with a high processing throughput
- high speed 12 bit data conversion in the data acquisition unit
- use of modern technology components with low power dissipation
- modern memory devices
- capability of interrupts
- possibility to synchronize the real time clocks (if there is more than one)
- galvanic isolation of different lanes
- EMI, LEMP, NEMP protection
- self-calibration of the interface
- failure identification indication
- Built-In-Test capability
- testable via test connector and serial data link (RS232)

Nevertheless the comparison of the tasks of an auxiliary power unit (APU) and those of a fighter engine will clarify the big differences:

The auxiliary power unit will be active most of the time on ground to drive the generator and other auxiliary systems of the aircraft. Only in critical situations it will run inflight to provide additional electrical or hydraulic power.

Therefore a single control lane possibly with a special overspeed protection will fit the tasks mentioned under section 2 (fig. 3.1).

In detail, the control lane consists of the following modules:

- input interface
- serial interface (RS232)
- central processing unit
- output interface
- failure code store
- power supply
- additional testing capabilities for the sensors, which are inside the controller
- a programme for communication between the maintenance personal and the controller for reading out the BIT results via RS 232 interface.

BIT will be capable to localize detected hardware failures down to the level of the plug-in subassemblies with a probability greater than 95%. The results will be stored in a non volatile memory (e.g. EEPROM).

In contradiction the fighter engine has to power the aircraft on ground and in flight and very often there is only one engine available. In the case of any failure, caused by the engine itself or by its controller, there will be a critical flight situation. By this it is important that the reliability of the controller is much better than that of the engine. To achieve this, the controller will consist at least of two electrically segregated lanes (1,2) (fig. 3.2) /6/.

The overspeed protection consists of:
- frequency/voltage converter
- threshold value detection
- delay
- valve activation
- power supply

The failure detection will comprise a number of selfmonitoring procedures (keep alive circuit, estimating procedures, etc.) /6/. In the case of a failure the control functions will be degraded or an APU-shutdown will be initiated.

The safety system will supervise the internal lane bus, the programme flow, parts of the processor and internal circuits. Detection of a failure will initiate in most cases an APU-shutdown. As a minimum the following performance will be monitored by means of hardware and software methods:
- data flow and direction on the lane internal bus
- machine cycle time of the microprocessor
- memories
- input/output interfaces
- power supply validity

For safty reasons, the overspeed protection will be monitored by the control lane.

The Built-In-Test (BIT) will monitor the controller during power up and normal operation conditions. It will consist at least of
- hardware for interface stimulation and test point-access
- a programme to carry out the tests and to analyse the results
Individual sensors and actuators will be provided for each lane, which will have its own processing control unit. Additionally, there will be a special supervisor, which will control the engine in case of failures in both lanes, e.g. it will control the engine to a special uncritical speed. In detail each lane will consist of the following modules:

- input interface
- serial interface (RS232)
- central processing unit
- output interface
- failure code store
- power supply
- data link to the other lane

There will be a switch in the cockpit to select one lane, the other lane will be put into standby position. In case of a single failure, detected in the selected lane, a switch-over to the other lane will be initiated and a signal will be given to the cockpit. The two lanes will be identical in terms of performance, so that normal engine control will be ensured.

For failure detection the same methods mentioned for the auxiliary power unit will be implemented. In case of a second failure detected in the fault-free lane the system will revert to special conditions, such as freeze or shutdown.

The safety system will have exactly the same design as for the APU with only one difference:

- the tasks to be done are bigger and will force more hardware circuits, memories and execution time.

The supervisor system will be independent of the safety system and will mainly be used to monitor critical engine parameters, e.g. the high pressure spool speed. This additional supervisor system together with the safety system will raise the failure detection capability to the level satisfying the overall integrity requirements.

The BIT is comparable to that of the APU with the only difference, that more hardware circuits and sensors has to be tested.

As a result of this totally different design the only possibility in using the same hardware for the controllers of different types of engine is to use one lane of the redundant fighter controller for the auxiliary power unit. The reason for this is, that nobody will spend weight and volume and therefore money for unnecessary electronics.

To find out if this solution makes sense, one has to examine the problems in more detail.

It should be noted at this position, that there may be due to customer requirements, more discrepancies, such as special data bus (e.g. MIL-BUS or ARINC 429) or dedicated serial data links. For further comparison these additional requirements should be ignored, especially as more and more all systems will have these connections.

3.2 Input/Output Requirements

Figure 3.3 shows the input/output interconnections of the controller of an auxiliary power unit.

In detail there are:

- high pressure spool speed (monopol)
- low pressure spool speed (if any) (monopol)
- load compressor inlet temperature (resistor or thermocouple)
- load compressor discharge temperature (thermocouple)
- engine gas temperature (thermocouple)
- fuel metering (flow meter or LVDT)
- guide vane positions (LVDT)
- inlet pressure

With the exception of the speed sensors which generate frequency signals, all other sensors are analogue types.

The pressure transducer should be installed inside the controller, in spite of the fact, that the environment of the APU is not very dangerous due to temperature and vibration. If the transducer is engine mounted, the transformed electrical pressure signal has to be protected against EMI, LEMP, etc.
The output signals can be separated into 3 major groups:
- Serial data output (RS232)
- Engine and control parameters
  * Fuel torque motor
  * Fuel solenoid valve
  * Start relay
  * Generator output
  * Surge control valve
  * Load control valve
  * Ignitor
- Discrete outputs

The required printed circuit board area for the signal conditioning for all these input and output signals will be some 500 cm²/cm. The volume for the pressure transducers and the EMI/LEMP/NEMP-protection measures will be roughly 500 cm³/cm. The power consumption will be about 30 watts.

Figure 3.4 shows all input and output signals of the controller of a fighter engine.

- High pressure spool speed (monoprop)
- Low pressure spool speed (monoprop)
- Intake total temperature (resistor or thermocouple)
- High compressor inlet temperature (thermocouple)
- Fuel flow metering (flow meter or LVDT)
- Nozzle shroud position (LVDT)
- Inlet guide vane position for different spools (LVDT)
- Special reheating signals

The hardwired are the following:
- Lane select switch
- Inhibition signals
- Spares

The light signal is only induced by the turbine blade temperature pyrometer (fig. 3.6).

![Flexible fibre optic light guide](Image)

**Figure 3.4 Possible Input/Output Interconnections of the Controller of a Fighter Engine**

Overall there are about 20 different input parameters from the engine, about five input parameters from aircraft sensors and flightdeck condition informations hardwired to the controller, about 13 different output parameters to the engine and a few output parameters hardwired to the cockpit.

The input parameters can be separated into three major groups:
- Electrical signals
- Pressure signals
- Light signals

Except for the power lever angle (PLA) and the hardwired ones all electrical signals are coming from engine mounted sensors which have to measure the following parameters:

**Figure 3.5 Schematic of a Pyrometer**

The pyrometer are very fast and can measure high temperatures but they are very expensive, so that they are used only for big engines. These pyrometers will directly be connected to the controller via fiber optics, to provide the information required by the infrared photodetector which will be installed in the controller.

Apart from the photodetector the pressure sensors will be installed into the controller, too. These sensors will be connected to the engine via multiple hydraulic plugs (fig. 3.5) and pressure tubes.
levels, so that they will need different signal conditioning. Also the discrete inputs and outputs can be different (28v/open, open/ground).

3.3 Central Processing Unit

Normally the central processing unit (CPU) is a special printed circuit board (PCB) which includes the microprocessor, the memories and the keep alive circuit (fig. 3.7).

![Figure 3.7 Schematic of the CPU (Central Processing Unit)](image)

State of the art are 16-bit processors and this type will fit the tasks of both engine types, unless special requirements (e.g. high accuracy) will force a 32 bit processor with all consequences to the choice of the analogue to digital and digital to analogue conversion (16-bit conversion rate instead of 12 bit).

The required space of the memory depends of the different tasks of the controller and normally the controller of the APU will use less space than that of the fighter engine. The technology of the keep alive circuit will be the same.

3.4 Other Hardware Elements

The design of the power supply could be equal, but due to the fact, that the power consumption is different - the APU controller needs less than that of the fighter engine -, the design of the power supply will differ, otherwise it...
will not fulfill the specification or it will be too big and too heavy.

The filter block for EMI/LEMP/NEMP-protection will have the same electrical circuits for the same signal types but will differ due to the different number of signals.

The chassis of the controller will be high quality castings of a non deforming aluminium alloy. They will be impervious to EMI, spray water and other mechanisms in order to fulfill general requirements. Condensation will be prevented by the installation of pressure-equalizing filters. The pressure-equalizing filters will be composed of teflon felt and a gauze for EMI-tightness. They will be mounted on the bottom cover.

Easy accessibility of the electronic circuits will be achieved by lifting chassis side and bottom covers.

The controllers will be composed of E. Each module will be mounted on a high precision metallic frame on which the printed circuit boards (PCB) will be installed.

The small width between the attachments of the printed circuit boards will assure high vibration resistance. The frames will be attached to clamping devices. In this way a rigid unit with excellent heat transfer capability will be obtained. The heat transfer to the chassis will additionally be supported by laterally clamping the modules.

4. Software Configuration

Software is an integral part of engine controllers. On the basis of the specifications hardware and software will be developed in simultaneous parallel activities. The development paths will meet again when hardware and software will be integrated. After system certification the software has to be maintained.

The activities for development, verification and documentation are the following (fig 4.1):

- Software will be developed and integrated step by step. These steps are:
  * functional requirements
  * software requirements
  * design of software
    - general
    - detailed
  * coding and module test
  * module integration
  * hardware/software integration
  * validation
  * maintenance

- A verification step in which the result of the development step is to be verified by means of appropriate tests, will be assigned to each development step.

- For each development step accompanying documents describing all important development results are to be prepared.

- The beginning and conclusion of the individual development steps will be controlled by particular monitoring and release procedures (review and audits).

FIGURE 4.1 Software Lifecycle

In spite of the fact, that the software configuration for both controllers will be very similar, it shall be explained here.

Overall there will be eight different software tasks, which will be implemented in the controller in a modular manner:

- operating system
- application software
- input/output driver software
- standard routines
- safety/reliability
- Built-In-Test
- test software (exerciser)

In the following sections these tasks will be explained in more detail.
4.1 Operating System

The operating system will handle the different software tasks including all the synchronization problems, the memories and the interfaces. Due to the fact that the standard operating systems of microprocessors will not fulfill the realtime requirements of operational systems, a special design with a very little overhead in time and memory will be required. This operating system should consist of a simple core as well as modules to mechanize the operational tasks. By this it is clear that the special design of the operating system will be influenced by the tasks and therefore it may be different for the controllers of the APU and the fighter engine.

4.2 Application Software

The application software will consist of the control software. The algorithm as well as their logical and timely connections will be mechanized via hierarchical structured modules. To have the possibility of modifications to be done after the certification the software has to be modular, which means that normally one module will contain only one separate function.

The main control tasks for the controller of the APU are:

- engine starting
- ignition
- acceleration control
- engine steady state control
- load compressor control (if any).

The control tasks for the fighter engine are very similar except that they are more sophisticated in some details. They exclude the load compressor control. Additionally the reheat control with

- sequencing
- ignition
- modulation
- nozzle area control

will be implemented.

The different fuel metering limitation functions as well as selection and reselection time will be implemented in the software.

4.3 Driver Software and Standard Routines

The driver software will be the interface between the application software and the hardware of the unit itself. By this sensor and consequently hardware modifications can influence this part of the software. The overall design can be the same for both controllers but in detail the different modules will be functions of the different input and output signals.

Standard routines, i.e. procedures which can be used common, will be stored in software libraries and by this equal and useable for different controllers. These procedures are e.g.

- mathematical functions
  (square route etc.)
- control functions
  (filters etc.)

Such functions are normally not available for microprocessors under the special aspects of operational software.

4.4 Safety and Reliability

The key words safety/reliability includes all software (and hardware measures, which will be used

- to monitor the correct function during operation
- to cut off faulty parts of the system
- and to degrade the function of the controller
- or to freeze respectively shutdown the engine

The different methods were already mentioned in section 3.1 and they are very similar for the controllers of both types of engines.

4.5 Built-In-Test

The Built-In-Test (BIT) will monitor and test the hardware and the software during power up and normal operation and will inform the aircraft- or maintenance crew in case of any failure. The normal operation monitoring will include the methods mentioned under section 4.4. As said in section 3.1 special programmes will be available to get all information of the system.

Also in this case the basic design will be very similar for both types of controllers but due to the fact, that the hardware design is different (sensors, actuators, signal conditioning, etc) the single modules will differ too.

4.6 Exerciser Software

The exerciser software will include

- the monitor
- and the different exerciser modules.

The monitor will be implemented and stored in the EPROM of the controller. Its task will be to provide the
possibility of communication between the maintenance crew and the controller and to control the different exerciser modules or programmes (e.g. testing step by step, read and write into and from the different memories).
The exerciser programmes will be available during development and operational phase and will be able to check special hardware and software parts. Normally they will not be stored in the EPROM and if both types of controllers have the same central processing unit the basic module can be the same.

5. Comparison

Section 3.1 has shown, that identical hardware for the controller of different types of engines can only be based on simplex lanes. Table 5.1 gives a summary of all different items discussed in the preceding sections.
The redundancy of the controller of the APU and that of a single lane of the controller of a fighter engine is equal, both have additionally a totally separate back-up system. Nevertheless the lanes are different in terms of
- data exchange between the lanes
- input/output interface circuits
- filter hardware
- software
- memory space
- special hardware for integrated sensors.

That means, that only the central processing unit and some hardware circuits and some software modules are exactly of the same design and can therefore be used for the controllers of both types of engines.

7. References

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B. Keiser
G. Dahl

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TABLE 5.1 Summary of the Differences of the APU Controller and the Controller of the Fighter Engine.