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

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Abstract

The technologie 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 harware concept
    - and 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 communalities too much differences (different number of inputs and outputs, data exchange to the redundant lane, more software etc) to design a cost-effectiv 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.

The effort of this paper is to point out the reasons for the need of special controllers for different engine types by comparison of the requirements and technical solutions for the controller of an auxiliary power unit and a fighter engine (fig. 1.1) /2/.
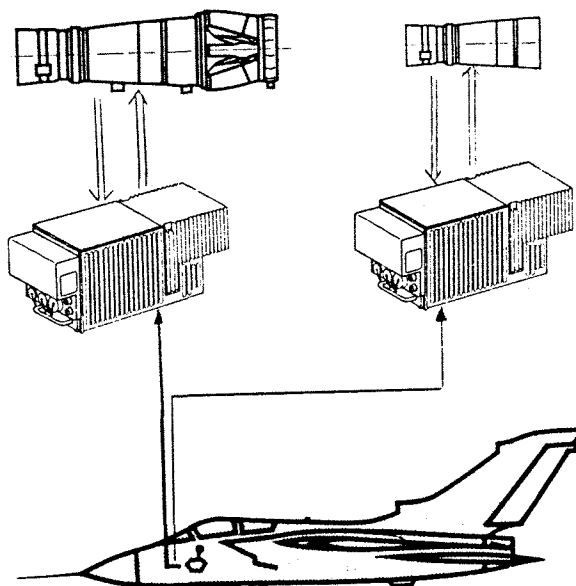

FIGURE 1.1 Fighter Aircraft with Engine and APU and their Controllers.

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 powerfull 16 bit microprocessor of the latest generation with a high processing throughput
- high speed 12 bit data conversion in the data aquisition 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 and failure code store
- 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 hydraulical 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
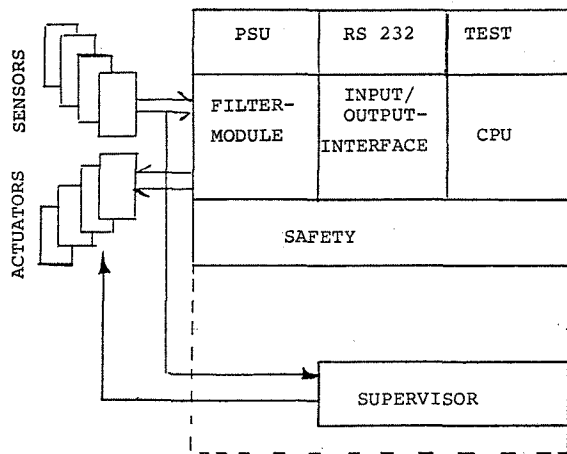- failure code store
- power supply

FIGURE 3.1 Blockdiagram of an APU
         Controller

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

- 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.
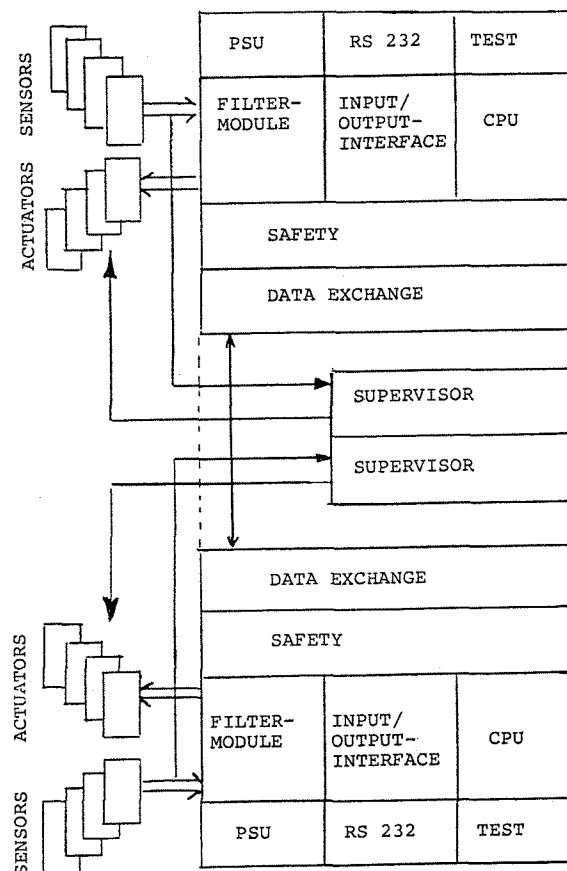3.2) /6/.

FIGURE 3.2 Blockdiagram of the
         Controller of a fighter
         Engine

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.

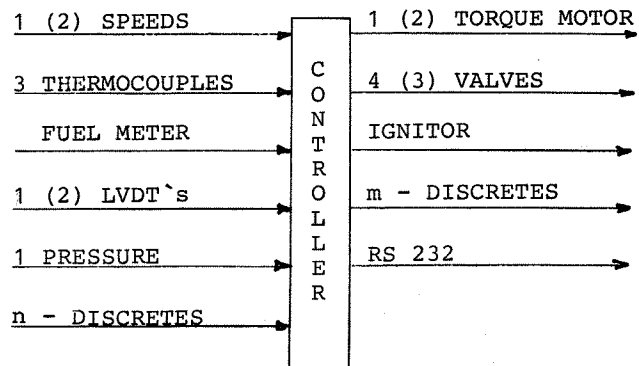| 1 (2) SPEEDS | | 1 (2) TORQUE MOTOR |
3 THERMOCOUPLES	C O N T R O L L E R	4 (3) VALVES
FUEL METER		IGNITOR
1 (2) LVDT's		m - DISCRETES
1 PRESSURE		RS 232
n - DISCRETES		

FIGURE 3.3 Possible Input/Output
             Interconnections of an
             APU-Controller

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 seperated 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 cm*cm. The volume for the pressure transducers and the EMI/LEMP/NEMP-protection measures will be roughly 500 cm*cm*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 (monopol)
- low pressure spool speed (monopol)
- intake total temperature (resitor 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 reheat 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).

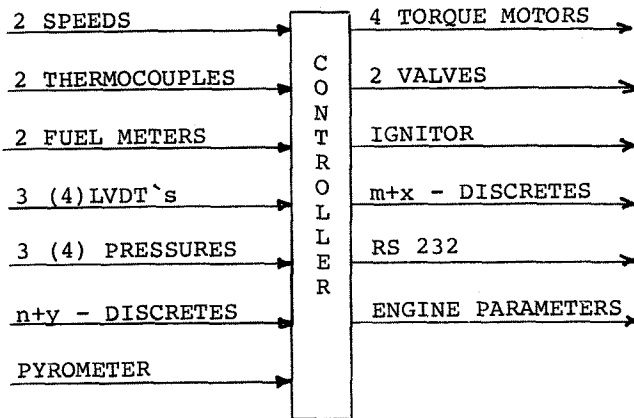| 2 SPEEDS | CONTROLLER | 4 TORQUE MOTORS |
2 THERMOCOUPLES		2 VALVES
2 FUEL METERS		IGNITOR
3 (4) LVDT's		m+x - DISCRETES
3 (4) PRESSURES		RS 232
n+y - DISCRETES		ENGINE PARAMETERS
PYROMETER		

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 seperated into three mayor groups:

- electrical signals
- pressure signals
- light signals

Except for the power lever angle (PLA) and the hardwired ones all electrical signals are comming from engine mounted sensors which have to measure the following parameters:
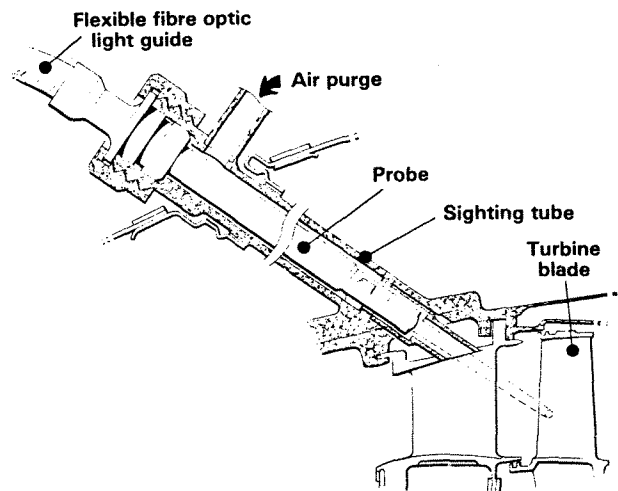
FIGURE 3.5 Schematic of a Pyrometer

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 plug (fig. 3.5) and pressure tubes.
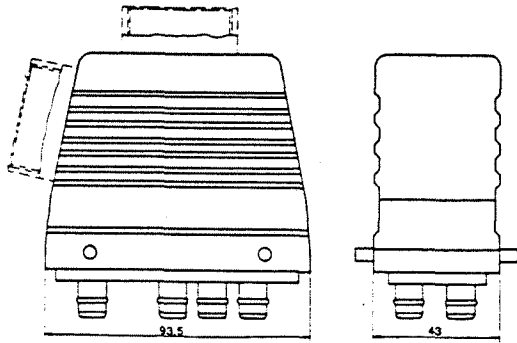
FIGURE 3.6 Schematic of a Multiple
Hydraulic Plug

For the fighter engine about four
different pressures will be measured. As
said above there are two reasons to
install the pressure transducers inside
the controller. First, the environment
at the engine is not very friendly,
especially due to high temperature and
vibration.
The second reason is the already
mentioned necessity to protect the
pressure signal after the electrical
transformation against EMI, LEMP, NEMP
etc.

The output parameters will be :

  - main fuel system demand
  - reheat fuel system demand
  - nozzle actuator
  - variable guide vanes
  - discrete demands
    * blow off valve
    * ignition
    * reheat select
  - engine and control parameters
    for aircraft system

The required printed circuit board area
for the signal conditioning for all these
input and output parameters will be some
1000 cm*cm. The volume for the pressure
transducers and the EMI/LEMP/NEMP-
protection measures will be nearly 1500
cm*cm*cm and the power consumption for
one lane will be roughly 50 watts.

It has to be noted that not only the
analogue signals have different signal

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
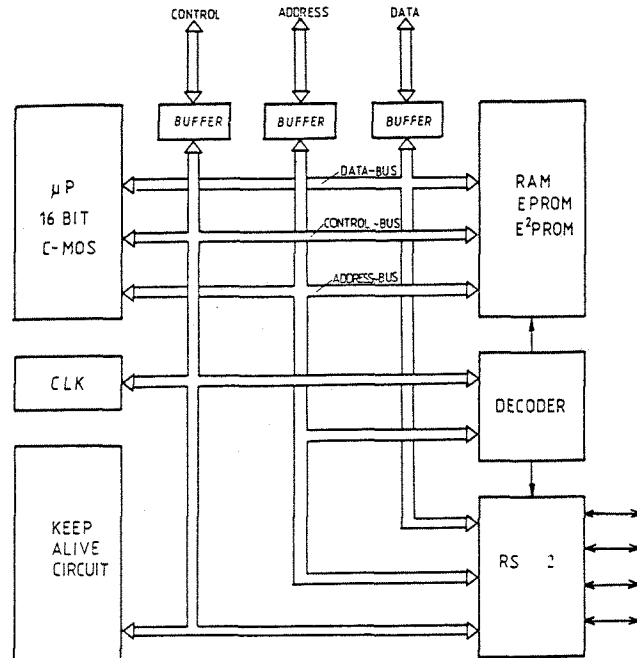(fig. 3.7).

FIGURE 3.7 Schematic of the CPU
(Central Processing unit)

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 diffent 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 mechanism
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
electronic modules. 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
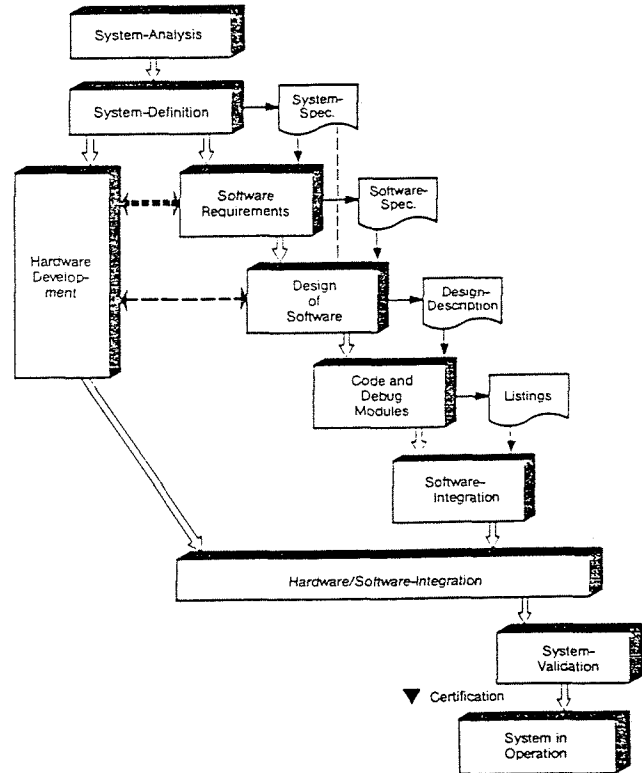 (review and audits).

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 sychronization 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 seperate 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 loadcompressor 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

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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 moduls can be the same.

5. Comparision

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 redundance 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 seperate 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 boths types of engines.

6. Conclusion

By comparison of the basic requirements and the main design characteristics in sight of hardware and software for the controllers of an auxiliary power unit and those of a fighter engine it could be shown, that a special design for special engine controllers will be more cost-effective than the design and development of a universal one. Only some special parts ʿ ˉ be used for different engine co. .rollers. Consequently it seems not very logical to follow the idea to have a very large board computer which will do the job of all the seperate controllers.

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                    for an Advanced Multi-
                    spool Engine
                    ICAS-82-4.7.3

	Redundance	Data Exch.	Input/ Output	Data Link	Filter	CPU	Soft- ware	Memory
APU	Simplex + Supervisor	-	x	x	x	x	x	x
Fighter Engine	Duplex + Supervisor	x x	xx xx	x x	xx xx	x x	xx xx	xx xx
One Lane of Fighter Eng.	Simplex + Supervisor	x	xx	x	xx	x	xx	xx

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