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EVOLUTION OF TURBOMECA'S TURBINE ENGINES CONTROL SYSTEMS

or

DIGITAL ELECTRONICS : WHY AND HOW ?

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1. INTRODUCTION

TURBOMECA always designed and built themselves the control systems for their engines. We first used purely hydromechanical systems, which progressively incorporated analog electronic parts.

We now turn to digital electronic systems. A non specialist could think that the main reasons for that turn were custom, weight, volume or price.
As a matter of fact three main reasons dictated us that evolution.

A - The recent technological evolution of turbine engines demands a precision in the control system that would have been very difficult to obtain with the previous techniques.

B - We wanted, along with the users, to incorporate new functions in our control systems, to make piloting surer and easier.
At the same time we wanted to use new methods for engine checking and maintenance.
All that would have been very difficult with mechanical or analog techniques.

C - Current availability of microprocessors allowed us to use them with a reasonnable fiability.
Presently the weight, volume, and price of design of such a first system are grossly equal to those of a mechanical one with its analog electronic ancillaries.
But, one, the obtainable performance and number of functions are far higher, and two, once experience is obtained through a first certification, the price of any new design should get dramatically down since it will only mean adapting existing software and changing the dimensions of the fuel pump and metering unit.

2. HISTORY

2.1 When in 1952 **TURBOMECA** designed the first helicopter turbine engine series produced in the world, **ARTOUSTE II**, it was a one spool engine, and it was decided to use it at constant speed. The control department then conceived and developed a tachometric hydromechanical governor with a proportional plus integral response, that worked quite well and, as well as its grand children now control the **ARTOUSTE** and **ASTAZOU** engines on a number of helicopters and aircraft, with in some cases the help of other mechanical *(fuel flow limitation by compressor delivery pressure)* or analog electronic *(control of starting fuel flow by turbine outlet temperature . . .)* devices.
A scheme is given in figure 1.

2.2 The first free turbine helicopter engine produced by **TURBOMECA** was the **TURMO III C3**, designed in 1959 to power the **SUPER FRELON** helicopter. The generator's fuel flow was controlled by the same tachometric proportional plus integral governor with a variable speed setting through the input lever. On the **SUPER FRELON** prototype, that input lever was moved by a twist grip on the collective pitch lever. Rapidly a cam, following the collective pitch lever's movements, was added. But soon the pilots got tired of controlling rotor speed by twisting the grip, so **AEROSPATIALE** developed an analog electronic rotor speed governor to replace it. Thus the complete system became one of the ancestors of recent free turbine engines control systems.

An interesting feature of this system was how generator's acceleration was controlled : a mechanical device gave a schedule in the form of NG = f (NG actual), (see fig. 2).
The starting fuel flow was scheduled as a function of ambient and compressor delivery pressures.

2.3 For the **TURMO III C4**, designed in 1967 to power the **PUMA** helicopter, the specification said the fuel control system should be as simple as possible. It was then made of (see fig. 3) :

A - A tachometric system : a flywheel driven by the free turbine acts directly on the metering plug, giving a proportional response :
FF = FFo – k N(FT).

B - Generator speed limiter : a flywheel driven by the generator acts directly on the pressure drop around the main metering plug.

C - An hydraulic clock limiting acceleration fuel flow.

D - Starting fuel flow scheduled like on the **TURMO III C3.**

Alas it soon appeared necessary to add a few complications : make the generator speed limiter ambient pressure sensitive, to counter an important drift in altitude, and incorporate in that limiter a double setting to introduce a double maximum power.

2.4 For the next generation engines, **ARRIEL** and **MAKILA**, in the years 1975-77, we came back to a principle, somewhat similar to that of the **TURMO III C3**, applied on most of the world's free turbine engines : (see fig. 4).

A - A tachometric governor for the generator. It keeps **TURBOMECA's** originality of having an integral action.

B - A tachometric governor for the free turbine, with a proportional action on the generator's speed setting.

C - A link between collective pitch and free turbine governor which decreases the rotor speed excursions, in stabilized regime by hiding the natural speed drop in the free turbine governor, and in transitories by anticipating orders.

D - Acceleration control giving a fuel flow as a function of compressor delivery pressure.

Figure 4 shows that for this new family **TURBOMECA** chooses a new technology : distribution spools are replaced by hydraulic potentiometers that need less high precision parts.

In the case of **ARRIEL**, the free turbine governor is mechanical, while in the case of **MAKILA**, which has a rear power shaft with no reduction gear, in order to obviate the need of a shaft as in the **TURMO III C4**, it is electronic *(analog)*.

2.5 For our next engines, such as **TM 333**, which flew for the first time at the beginning of last April, it was decided to go to a full authority, digital electronic system. The studies are made with government help (**DRET - STPAé**) in collaboration with **MATRA** and **ELECMA**.

3. RECENT TECHNOLOGICAL EVOLUTION OF TURBINE ENGINES

The present trend is towards an increase of temperatures and pressures to improve s.f.c. and of the load of each stage to simplify engines and lower the weight.

Let us compare for instance two engines, designed at an interval of slightly more than ten years.

Engines	Compressor	Turbine	P. ratio	Turbine T°C
TURMO III C4	1A + 1C	2 + 1	5.7	920
TM 333	2A + 1C	1 + 1	11	1 100

The total number of stages is the same, but pressure ratio has nearly doubled while the temperature increased by nearly 200° C without blade cooling. In the case of the **TM 333** we also used variable setting inlet guide vanes to improve efficiency at partial power.

The result of all these evolutions is that the last percents of N.G. give more and more power, at the price of more and more temperature rise. For these two engines 1 % less N.G. means respectively 4.2 and 7 % less power, while 1 % more N.G. means 20 and 32° C.

At the same time, our wishes for control precision are tighter : we could accept a 20° overheat twelve years ago, but now we want to limit it to 10°, which demands a .3 % speed control. As a matter of fact our present aim is .15 or .2 %.

We already knew how to govern a maximum speed to ± .3 % at sea level on a standard day with a new hydromechanical integral control system.

But a proportional system such as the N.G. limiter in the **TURMO III C4** has, by conception, a speed drift as a function of fuel flow. The pressure capsule gives a good correction, but with all the tolerances, the speed drift in altitude can go up to 1 % or more.

A mechanical tachometer is sensitive to the temperature of its components. These variations can be compensated correctly at a stabilized temperature, but at take-off with a cold engine the temperature rises very quickly. It is again sensitive to the density of the fluid around the flywheels. For instance you loose about .5 % when changing from JP1 to gasoline without resetting. In the case of cavitation or use of fuel containing air bubbles, it can be more serious. Technical solutions exist, on the paper, but they have never been used, for they should lend to more volume and weight.

It is in the solution of that problem of tachometry that the digital technique offers a radical progress. It is possible, by counting pulses, with a high enough frequency, to make that measure within 1 ‰ .There is an improvement also in the solution of stability problems, for the coefficients of the control equation can be changed when necessary instead of being the result of a compromise.

4. NEW FUNCTIONS TO BE INCORPORATED

In most of present control systems maximum ratings such as Take-Off, Max Contingency or Intermediate Contingency are materialized by colour marks on an instrument. But tachometers are rarely better than 1% and temperature indicators can be relied upon after several seconds, if not tens of seconds. More over when the pilot uses one of these ratings he is already pretty well work loaded and cannot give all his attention to engine parameters.
So we think, along with users, that any of these settings must be either positively governed or easily readable on a difference indicator. Then these limits can be varied as a function of ambient conditions.
Users wish in some cases to vary rotor speed.
Presently, to check the state of an engine, and specially that it can deliver M.C. power, the user has no alternative to using it at that power. Doing so, he uses precious minutes of engine time at maximum allowable temperature. A performance computation at partial power, by comparison to the guaranteed engine performance, associated with the governor functionning properly, is enough to be sure the engine will give you the power.
Creep and crack life of the engine can also be computed from the same parameters used in the control system.
Present training, to be realistic, must be done at maximum weight. This means a risk, and, as before, a consumption of high price time on the engines. It is possible to make a realistic training with lower maximum powers and weight. Risk is then limited by the possibility of going back to normal max power.

5. OUR ELECTRONIC DIGITAL CONTROL SYSTEM

First here are a few conclusions of our preliminary studies.

A - It will have a full authority. Otherwise the study would not be worth while.

B - The system must detect and signal its failures

- In the case of a small defect, performance can be lowered.
- In the case of a serious failure, there will be neither run up nor run down. Fuel flow should be fixed where it was when the failure occured *(inactive failure).*

C - A manual back-up must be able to give more than half the power needed in the most critical condition, and to idle and cut the engine, whatever was the fuel flow at the time of the failure.

D - Except for the tachometric measure, we should not rely upon high precision sensors, which are expensive. It means that in most cases we shall use closed loops.

Using these conclusions, here is what we did.

- *Engine control in normal flight :*

  We use the current formula : generator tachometric *(integral)* governor, proportional free turbine governor setting the generator governor, power lever anticipator.

- *Maximum setting :*

  T.O. setting is not limited. The computer delivers a signal proportional to the difference between N.G. *(T.O.)* and N.G. actual. The helicopter maker can use it.
  At any time, the engine can wind up to Max Contingency power which is limited. N.G. *(M.C.)* is a function of ambient temperature. The pilot just monitors his rotor RPM.
  When the Max. Contingency allowed time is up, the computer signals the pilot that he should go to Intermediate Contingency. An action is needed *(for instance depress once a button on the pitch lever)* to lower maximum RPM to N.G. *(I.C.)*. That state is signaled. In case of absolute necessity the same action gives N.G. *(M.C.)* back.

- *Training :*

  An action from the teacher, plus idling one of the engines lowers N.G. *(M.C.)* and N.G. *(I.C.)* by the same amount. Cancellation of the teachers order, or switching the other engine back to normal, restores normal limitations.

- *Engine control :*

  Each engine is controlled by a three position switch :
  1) Stop — 2) Start or idle — 3) Normal

- *Accel - Decel :*

  Presently they are limited by fuel flow as a function of compressor delivery pressure. Later it will be a dNG/dt = f (N.G., ambient pressure) and ambient temperature if necessary.

- *Super idle :*

  Engines being at idle, action on the rotor brake lowers the idling N.G. to allow rotor stop. When starting an engine with the rotor brake engaged, it will stay at super idle till the brake is released.

- *Rotor RPM change :*

  The pilot is offered a switch.

- *State signals :*

  The following states are signaled : stop, start, super idle, idle, normal, I.C. power needed, I.C. power engaged.

- *Defects and failure signals :*

  Three different levels of signaling :

  1) Loss of redundancy : no immediate action. Maintenance action will be needed.
  2) Defect altering performance *(acceleration or power)* : no immediate action. Precaution will be needed.
  3) Failure. Fuel flow is fixed. After a critical phase termination, the pilot will have to set the fuel flow manually.

- *Inlet guide vanes setting :*

  This control loop is functionnally separate, for it is still necessary when on manual. A separate computer *(analog)* does the job on «normal». If it fails, the main computer takes over and signals it *(redundancy loss mode).*

- *Overspeed cut off :*

  It is a separate computer *(analog)* for the same reason.

- *Power supply :*

  As asked by regulations, normal power supply is from an independant alternator on the engine. Aircraft power backs it up

  - in case of failure of the alternator.
  - during the early stages of a start.

6. HOW WE DEVELOPED AND TEST IT

After usual development on the table, on a simulator and on a test bench engine, each circuit is flight tested on a known engine. From May 1980 we flew a control system on an **ASTAZOU III - GAZELLE,** with just a tachometric governor and starting system : FF = f (N,T4). From November 1981 we flew two systems on a **MAKILA-PUMA,** with a full lot of generator, free turbine, accel-decel, max powers, etc... Only the I.G.V. control could not be tested, through lack of a proper engine. On the same **MAKILA-PUMA** we are presently flying the dNG/dt accel-decel circuit, before adapting it to the **TM 333.** Tests on the **TM 333** are flown on a **SA 365 DAUPHIN** twin-engine helicopter.

7. CONCLUSIONS

The turn to digital technique has demanded and will demand an enormous work. As and perhaps more as for any new technique, each step is associated with serious difficulties which, on an afterthought will seem benign.
Nevertheless our opinion is formed :

- we shall obtain certification in the Spring of 1985.
- the trend towards this technique is irreversible.

The engine constructors who don't make that effort will be obsolete.

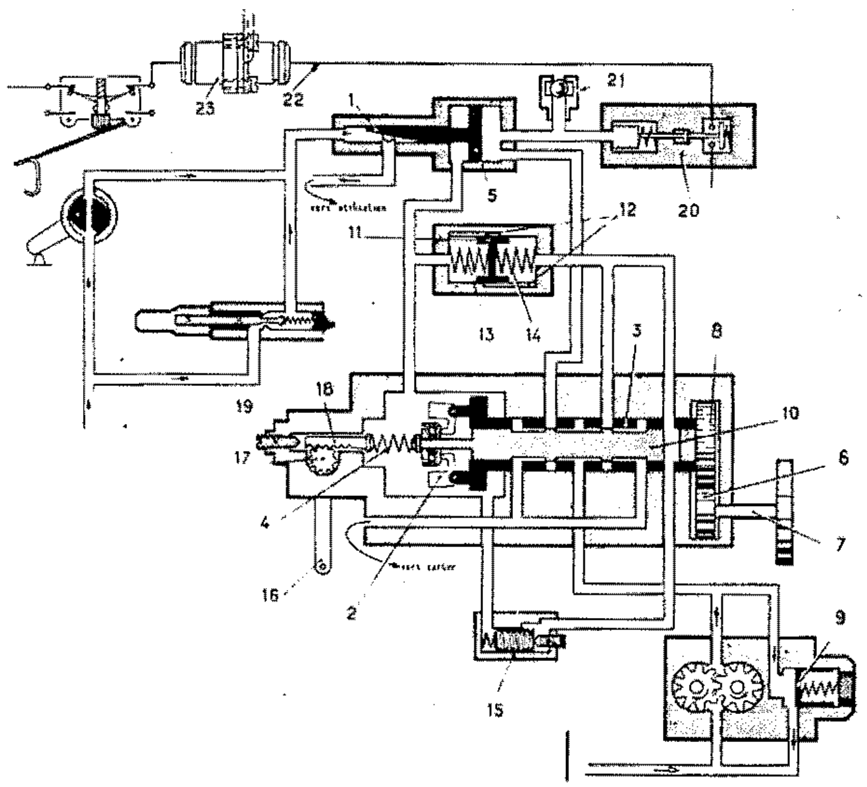


Fig. 1

ARTOUSTE II

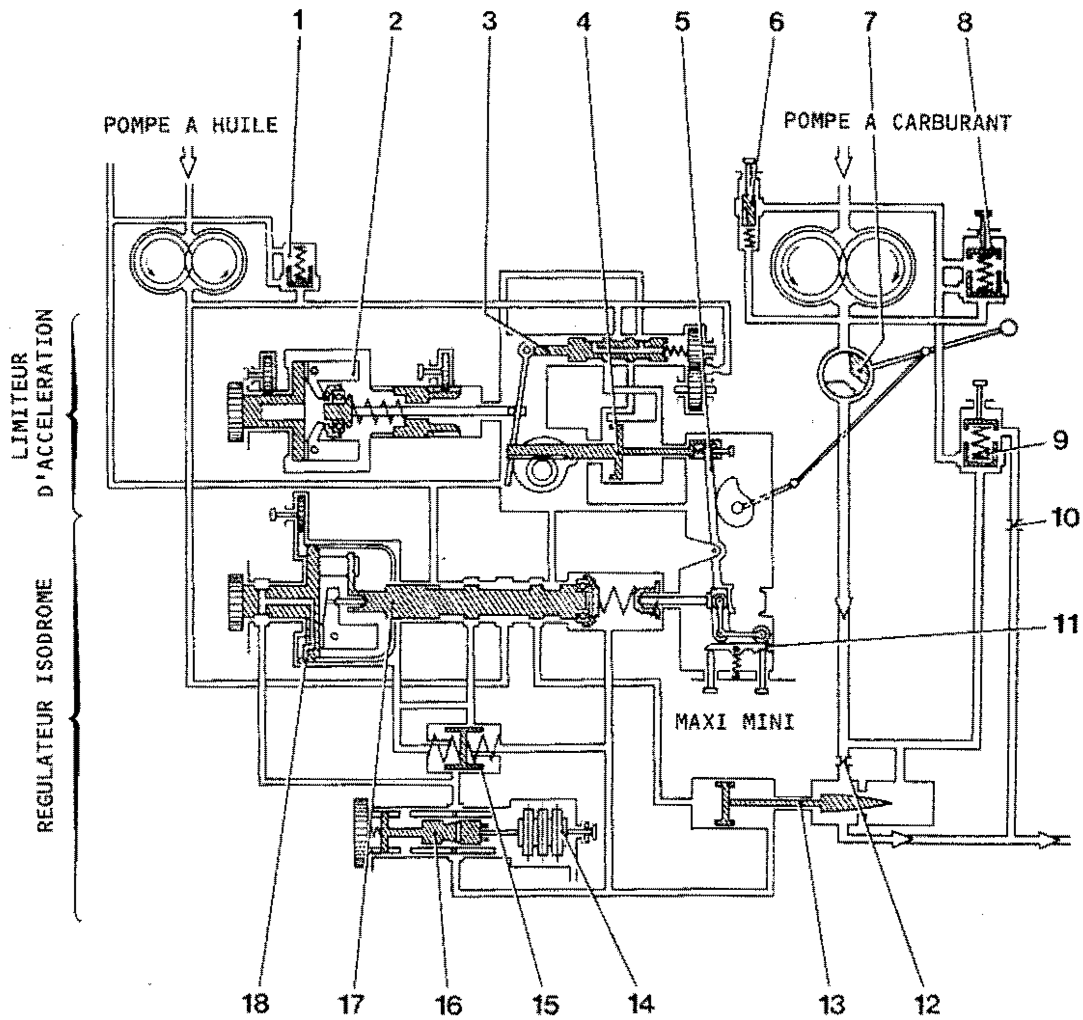


Fig. 2

TURMO III C3

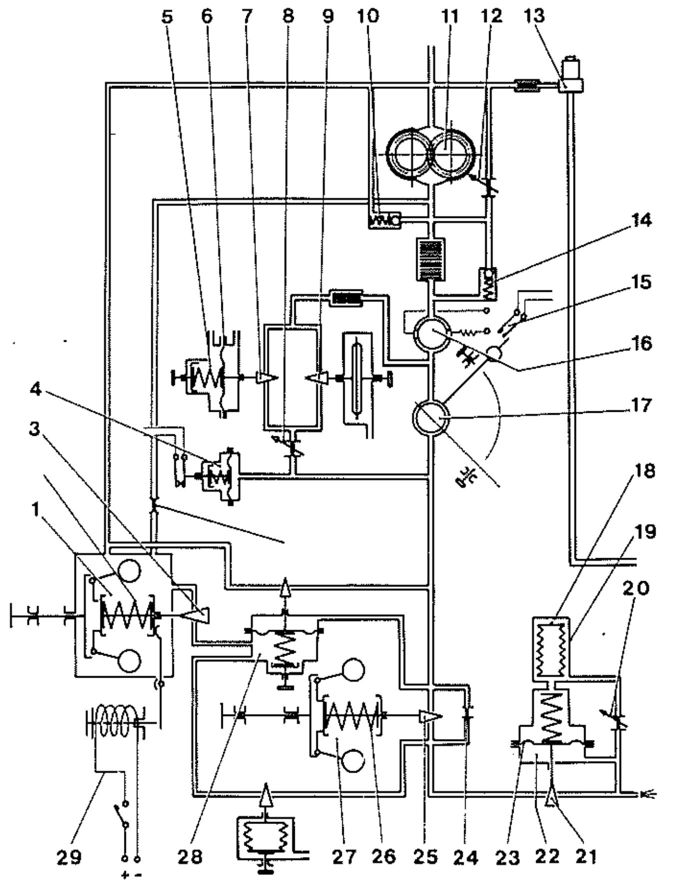


Fig. 3

TURMO III C4

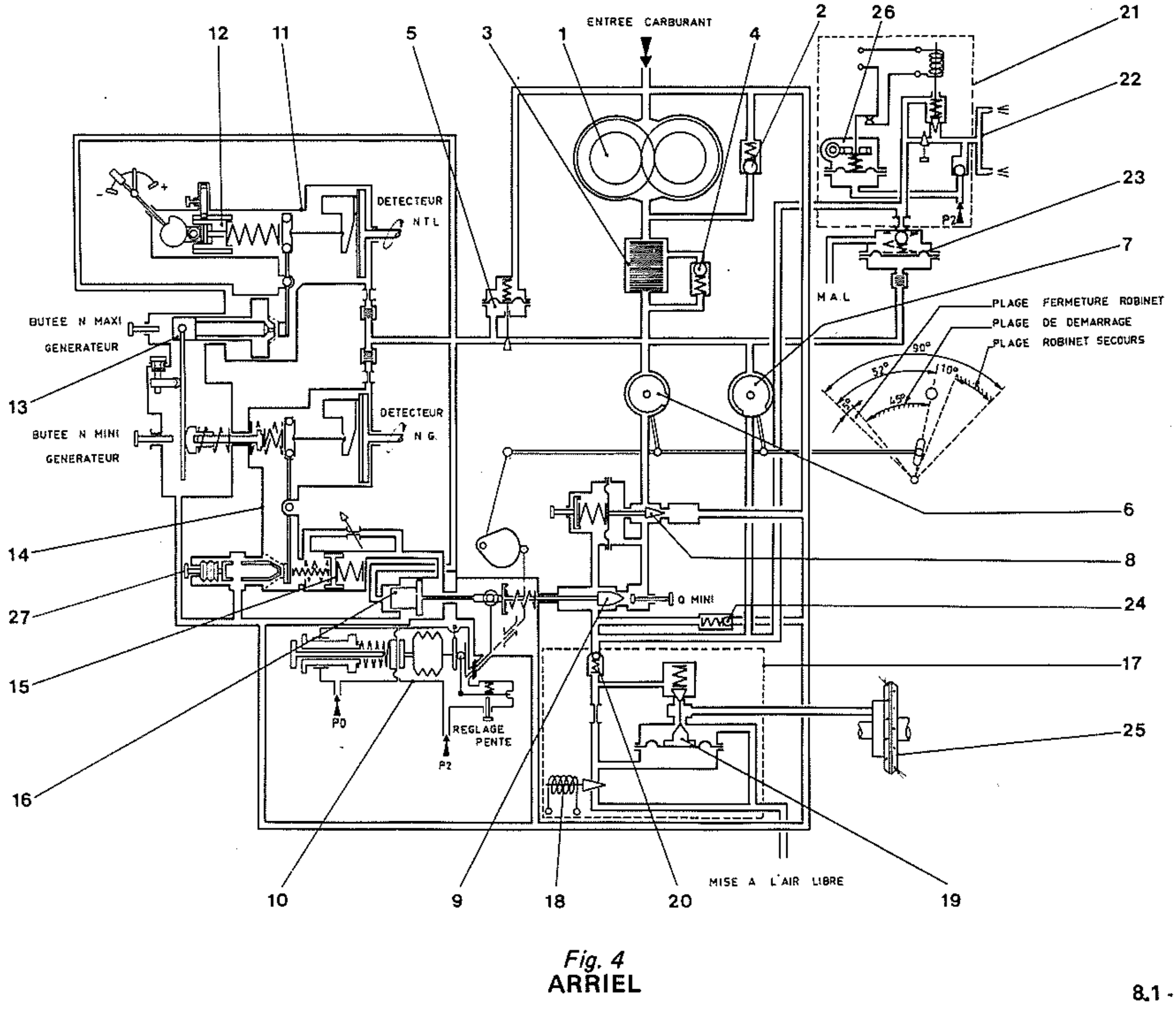


Fig. 4
ARRIEL

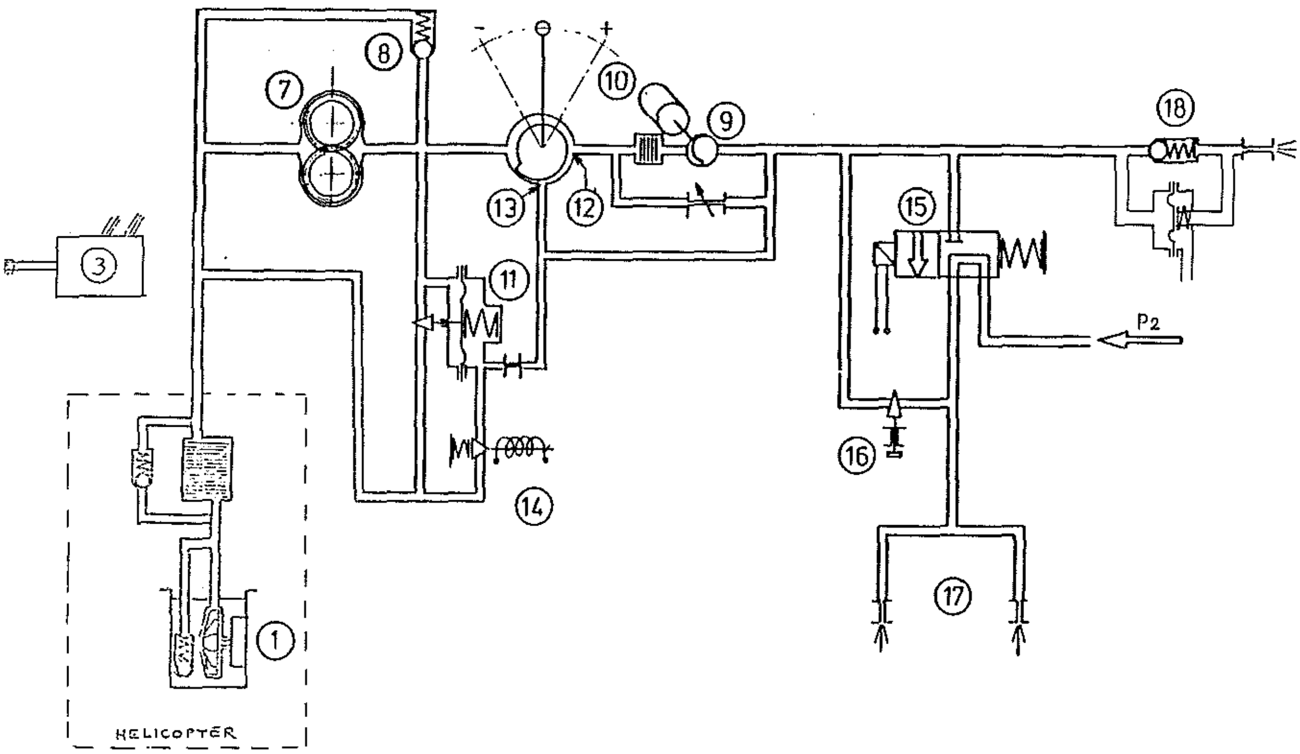
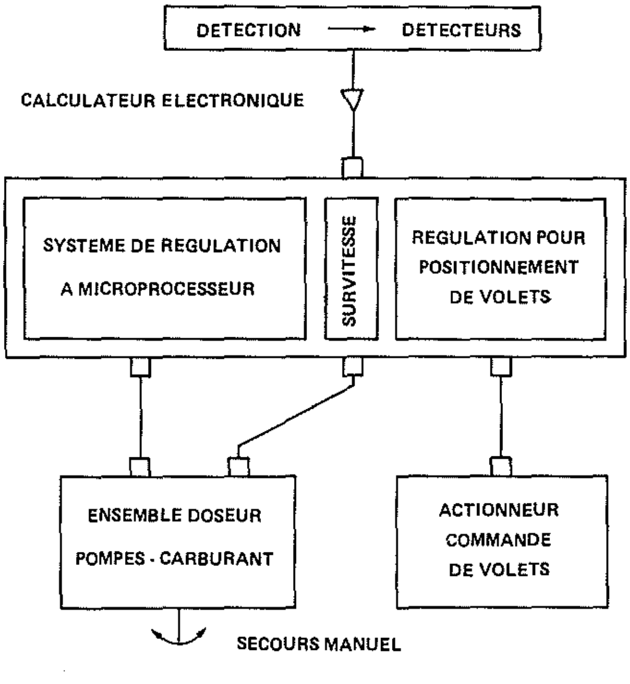


Fig. 5

TM 333



- Electronique à autorité totale
- 2 boucles de régulation fonctionnellement indépendantes :
  - régulation de vitesses N_G et NTL
  - régulation de position des volets d'entrée d'air

  comprenant chacune :

  - son alimentation électrique autonome (alternateur)
  - son dispositif d'auto-surveillance (détection et signalisation des pannes)
  - son dispositif secours (manuel pour régulation de vitesses, automatique pour régulation de position des volets d'entrée d'air)
  - son bloc hydromécanique de puissance
- Un dispositif de sécurité Survitesse Turbine libre

Fig. 6

TM 333