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EVALUATION OF A DIGITAL HELICOPTER CONTROL SYSTEM

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1. Introduction

In recent years, a number of studies have been conducted, sponsored by the German MOD, addressing new technology problems.

To mention some:

- multivariable control
- digital control
- technology of digital data procession
- computer aided design

The most important of them are merging in a realisation phase of the digital helicopter control system described herein.

2. Objective

The objective of this programme is to

- prove practical application of multivariable control in a helicopter application
- develop and demonstrate a digital control system
- demonstrate the integration of functions in one system
- demonstrate failure detection and isolation (fail soft).

3. Test vehicle

The test helicopter used for this programme is the BO 105-S 3.

This particular helicopter has been modified such that it can be flown conventionally from a safety pilot and with fly-by-wire equipment from the first test pilot.

Safety/switch over equipment allows the safety pilot to take over without any delay/synchronisation.

FIGURE 1: BO 105-S3

The test pilot in this modified helicopter is situated in the middle of the cockpit

4. Control concept

The BO 105 is controllable in four axis, roll, pitch, yaw and collective

Out of many possibilities for the manual mode of this control system, the following command control dedications have been selected:

stick pitch	commands	forward velocity
stick roll	"	sideward velocity
pedals	"	yaw rate
collective pitch	"	climb/sink rate

The concept requires that an input in one of the command branches shall be followed by the control system without any compensatory input in any other branch (decoupled system).

The theory used to control the helicopter is a multivariable state vector method. It requires that a set of sensor information, the state vector, is provided which fully describes the state of the process to be controlled.

In this case the state vector consists of the following 10 variables

V_{x_f}	- x-velocity (body axis)	r	- yaw rate
V_{y_f}	- y-velocity (" ")	ϕ	- roll attitude
V_{z_g}	- z-velocity	Θ	- pitch attitude
p	- roll rate	Ψ	- heading
q	- pitch rate	H	- altitude

The control system consists (in software!) of three basic terms:

$\underline{H}$ computes out of four pilot-demanded values the remaining variables to form a full demanded state vector

Trimmcomputation computes from a given forward velocity and altitude the trimm attitudes, velocities and control positions. The trimmcomputation is preprogrammed and mainly consists of tables.

K computes the contral law and is responsible for the system dynamic behaviour. The control law is adapted to changes in velocity and altitude.

The following signal flow diagramm shows the relations.

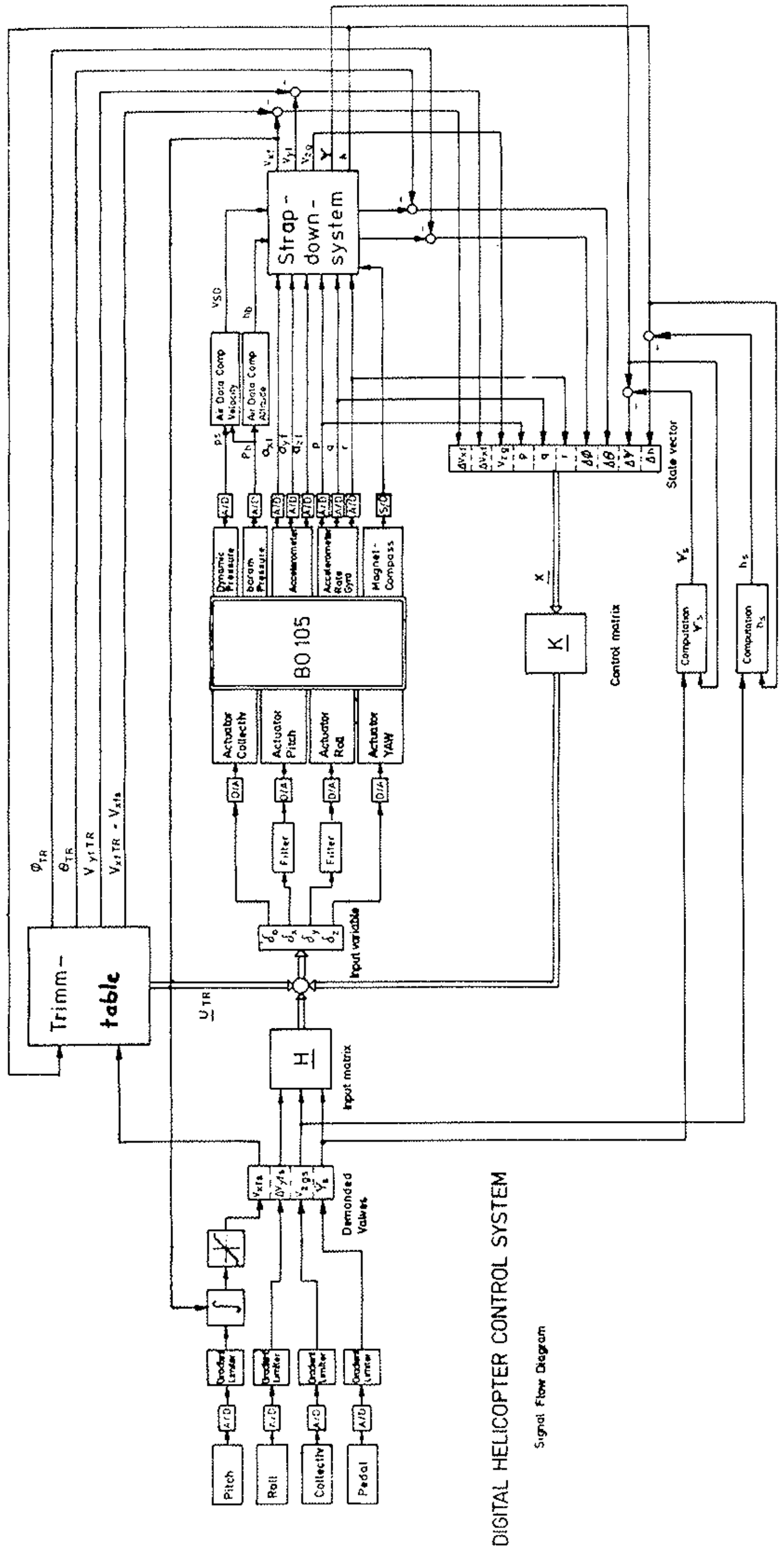


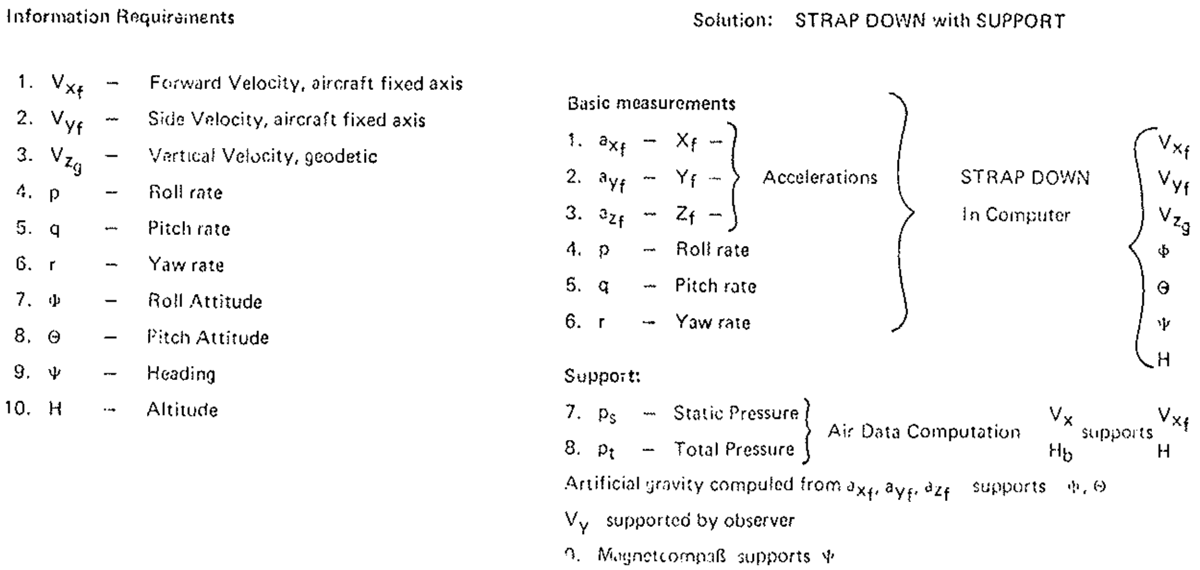
Figure 2

6. System realisation

6.1 Sensors

The control theory (4.) requires the availability of ten signals in the state vector.

They are measured and computed in the following manner:



Digital Helicopter Control System – Measurement Concept

Figure 3

During the course of the project, strap down has been proven to be a very effective means to provide many information with few sensors.

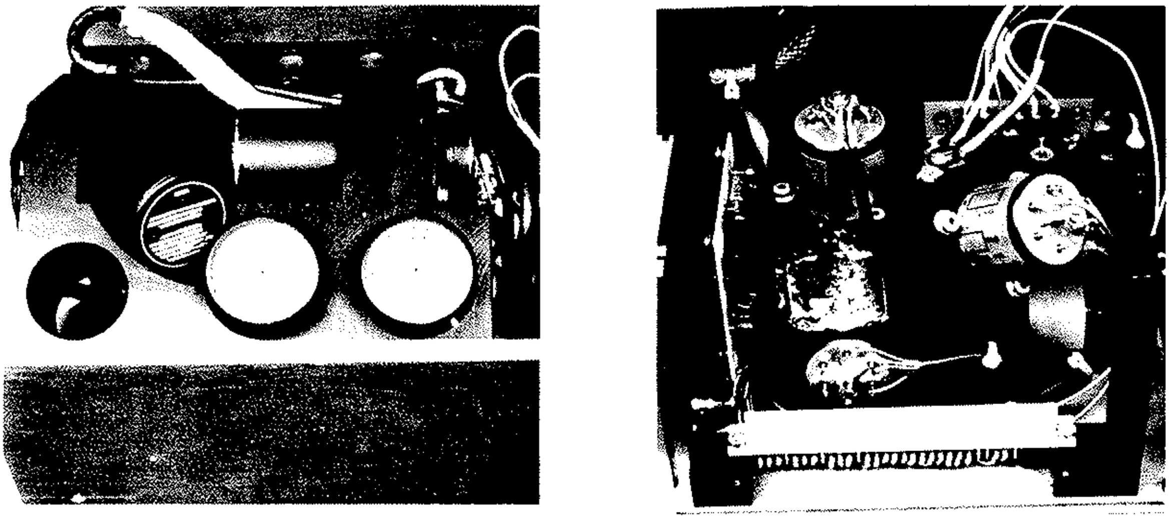


Figure 4:

Rate gyros and accelerometers used as basic (strap down) information.
The meaning of the fourth, skewed sensor will be addressed in chapter 7.

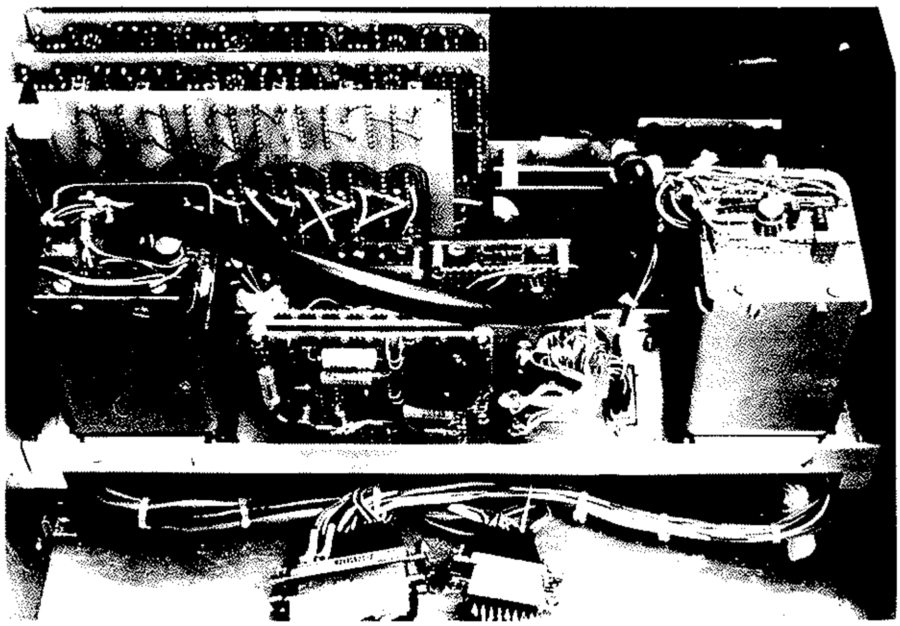
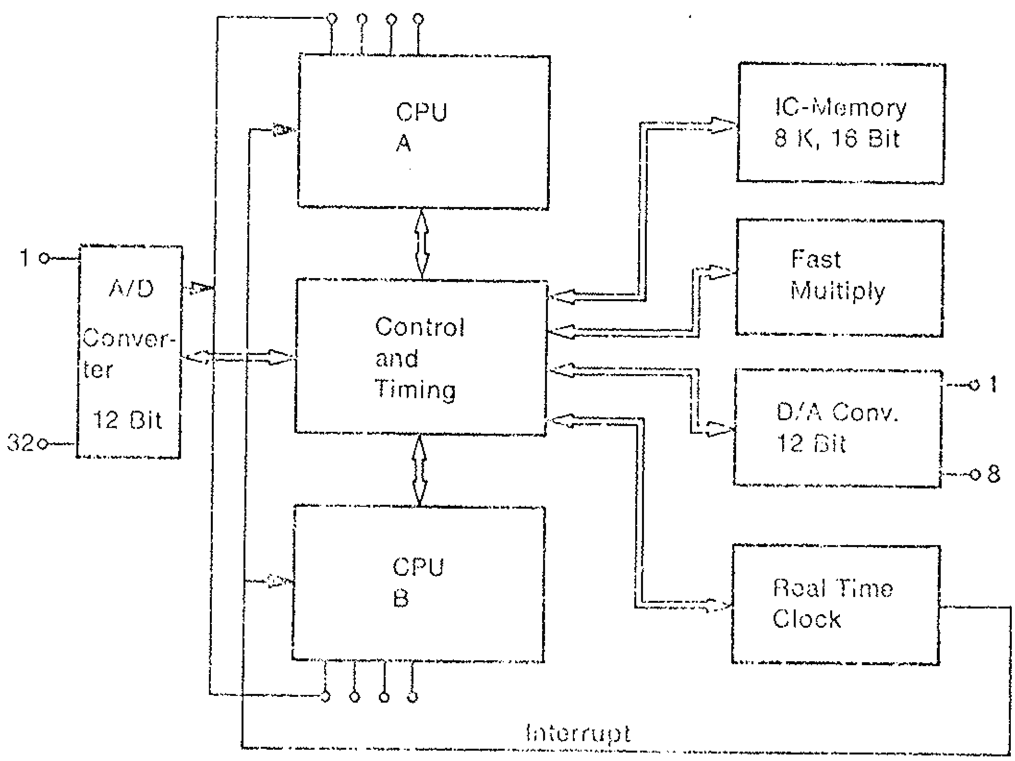


Figure 5:

Air Data sensors used for this project (static and differential pressure) are conventional, of the shelf equipment

6.2 Computer

The goal was to use small, inexpensive equipment with sufficient throughput to solve other than the stabilisation task. The selected CPU TDY 52 had not sufficient throughput but was inexpensive. The solution to the problem was a dual processor concept which also has been selected with regard to failure detection problems.



Digital Helicopter Control System
Computer Configuration TDY-52B-DK

Figure 6

From a hardware point of view only the CPU's are duplicated. However, from a users point of view this computer works like two computers. All tasks have been split in two groups executed by one or the other CPU. CPU A and B are communicating via memory.

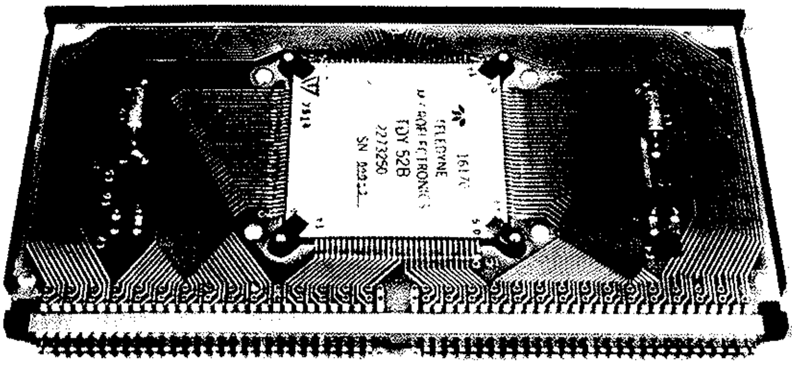


Figure 7:

Two TDY 52 B processors are forming the heart of the computer. One (hybridized) CPU is shown here.

One peculiar feature of the computer is the fast multiplication. It multiplies not only two sixteen bit numbers, with a thirty-two bit result. Software switch selectable the result can be automatically added to the previous result(s) of MPY.
This eases and speeds up all types of matrix-vector operations significantly. The fast MPY, like all other peripherals and I/O is accessable form either CPU.

6.3 Actuators

The electrohydraulic actuators are part of the basis test bed BO 105-S 3. The D/A converter of the computer provides DC-voltage to drive the actuators.

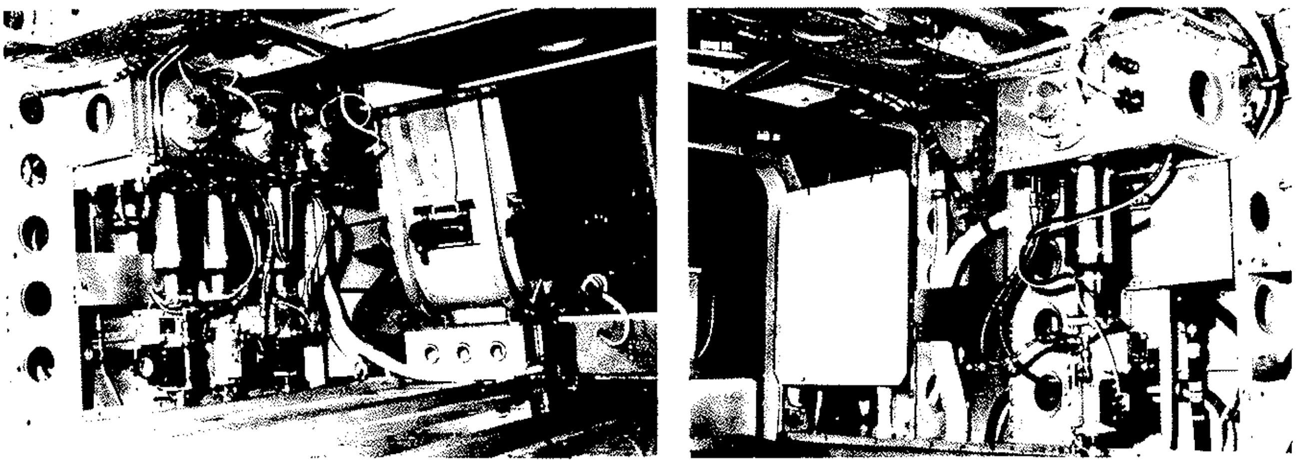


Figure 8:

Electrohydraulic acutators for the experimental DFBW. On top of each actuator a circular clutch is shown, allowing (by quick disconnect) the safety pilot to take over control of the helicopter.

7. Failure detection and isolation

7.1 Design requirement

Design requirement for this helicopter control system is to detect any single failure, indicate it to the pilot and disconnect the system before any failure consequence takes effect.

7.2 Failure detection

Different techniques have been used to detect failures in the sensor computer and actuator area.

7.2.1 Inertial sensors

Skewing technique is used which provides a fourth signal to monitor the three basic ones.

Sensor monitoring with Skewed Sensor

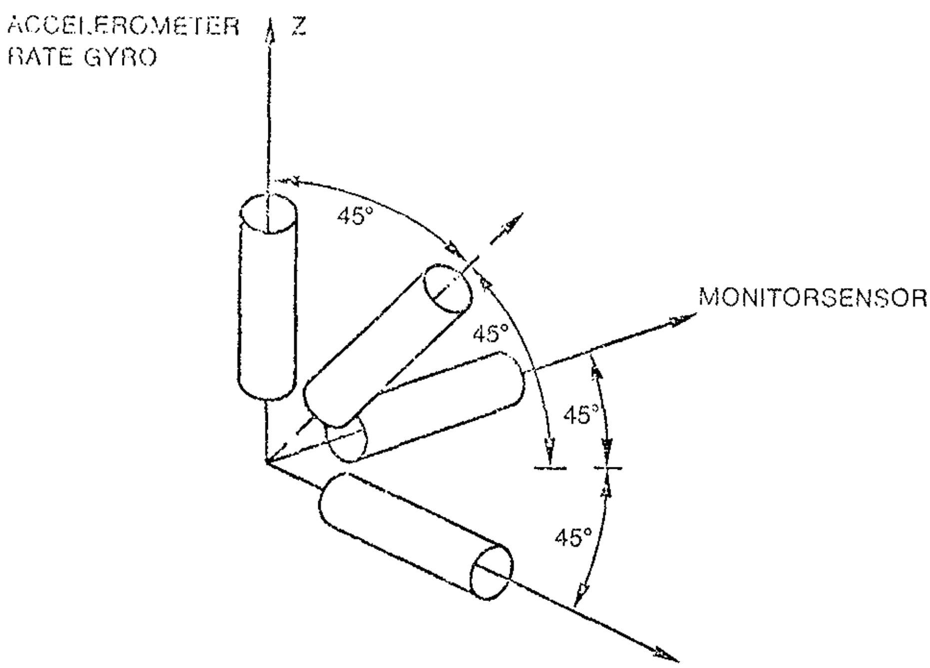


Figure 9:

Skewing technique is used to monitor accelerometers and rate gyros

The fourth signal is used to determine whether one of four fails. The control equation $s_c = a_1 s_x + a_2 s_y + a_3 s_z$ has to be fulfilled during failure free operation.
In the event of a failure, a failure localisation is not possible and not intended.

7.2.2 Pressure transducers

Pressure transducers are used for computation of air data equations.
x-Velocity and altitude are monitored against inertially derived results with appropriate thresholds for natural deviations due to wind and turbulence.

7.2.3 Computer

The dual processor solution has been selected particularly with regard to failure detection.

Each processor (see Fig. 6) performs as part of its task a check programme and compares the result with its companion CPU. In case of failure a discrepancy will occur.

7.2.4 Actuators

In this test programme no actuator monitoring has been implemented. However, model techniques are proposed for single channel realisations.

7.3 Failure isolation

Any failure occuring will be detected at least by one of the two CPU's in the computer.

The monitor in the following picture is a passive watch dog timer device. In case of a failure, this CPU detecting it, will not reset the monitor (as it frequently does during failure free operation). This causes a disconnection of the whole system. Relais etc. are duplicated. The disconnection is fail safe, works also in case of power loss.

A (duplicated) indication is given to the pilot.

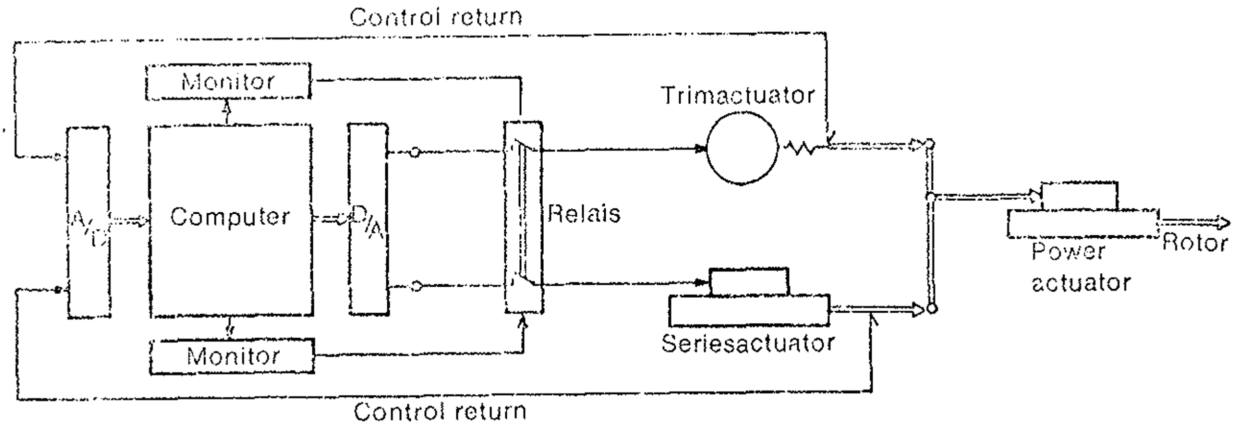


Figure 10: **Digital Helicopter Control System**

Principle of Actuator Monitoring

8. System functions

All system functions are performed by one computer.

The system provides

- Stabilisation (command control)
- Autopilot
- Air data computation
- Strap down computation
- Failure detection+isolation

9. Flight test results

9.1 Phase I

In phase I of this project, a totally different sensor concept (not described before) has been used.

Signals were derived from rate gyros, attitude gyros, pressure transducers, barometric altimeters.

This so called "utilize the already installed equipment" approach was unsuccessful. Sensor accuracy and drift rates have been found incompatible with the used multivariable control theory.

In addition coupling problems in the closed loop due to rotor blade dynamics have been encountered.

The sum of problems led the project close to a termination.

9.2 Phase II

In phase II the sensor concept has been totally changed to what has been described herein.

Digital and analog filters have been installed together with an extended state description. Elastic mode variables have been added to the control laws. Observers are providing the information about the elastic part of the state vector.

Phase II was concluded with a series of successful flight tests and good results, about which will be reported at another occasion.

The computer used in phase I and II was a PDP 11 mini computer mounted to a pallet.

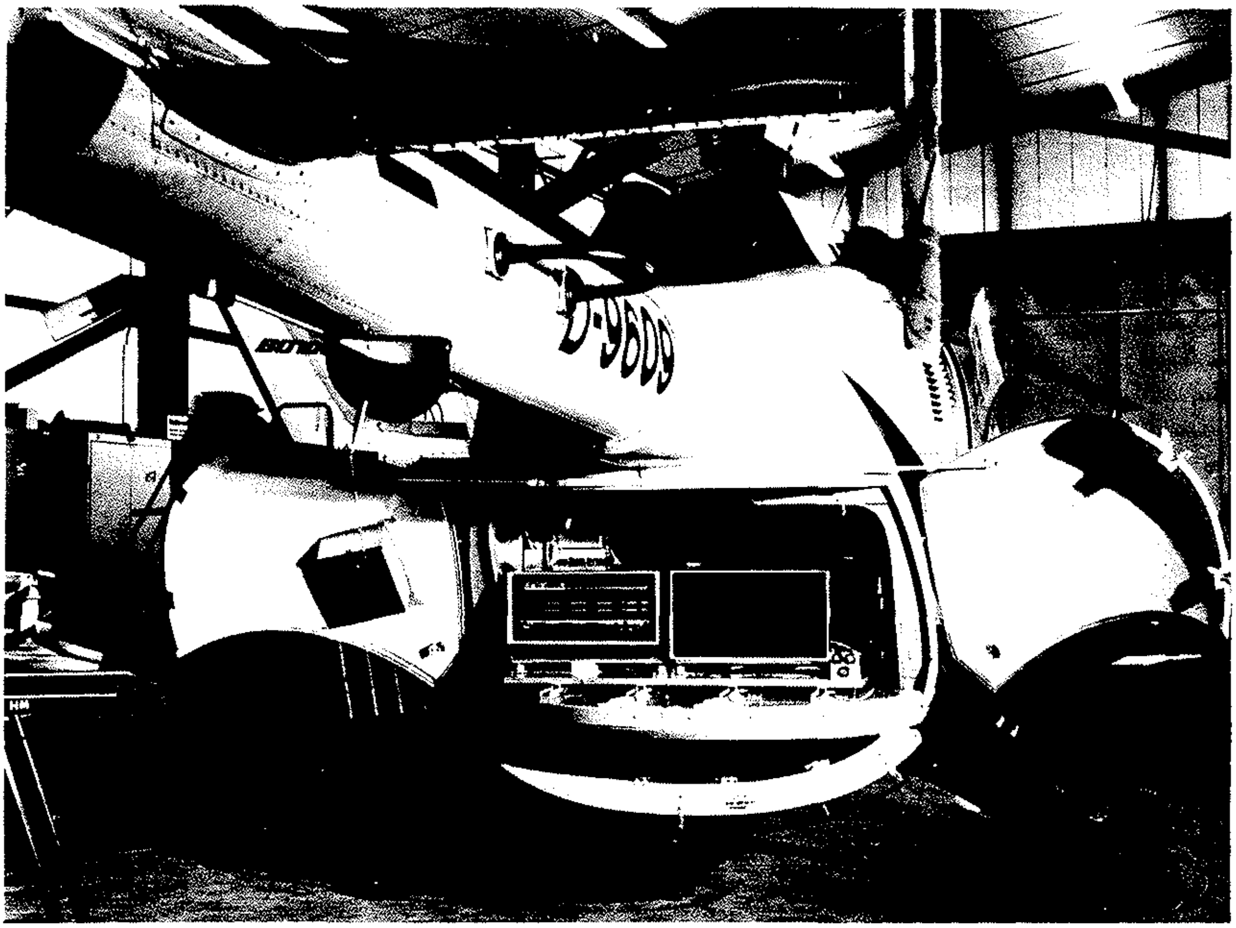


Figure 11:

PDP 11/20 minicomputer installed in the cargo compartment of the BO 105

9.3 Phase III

Phase III is commencing in late summer this year. Its task is to demonstrate phase II results with the original hardware. The computer now has been changed form PDP 11/20 to TDY 52-B-DK.

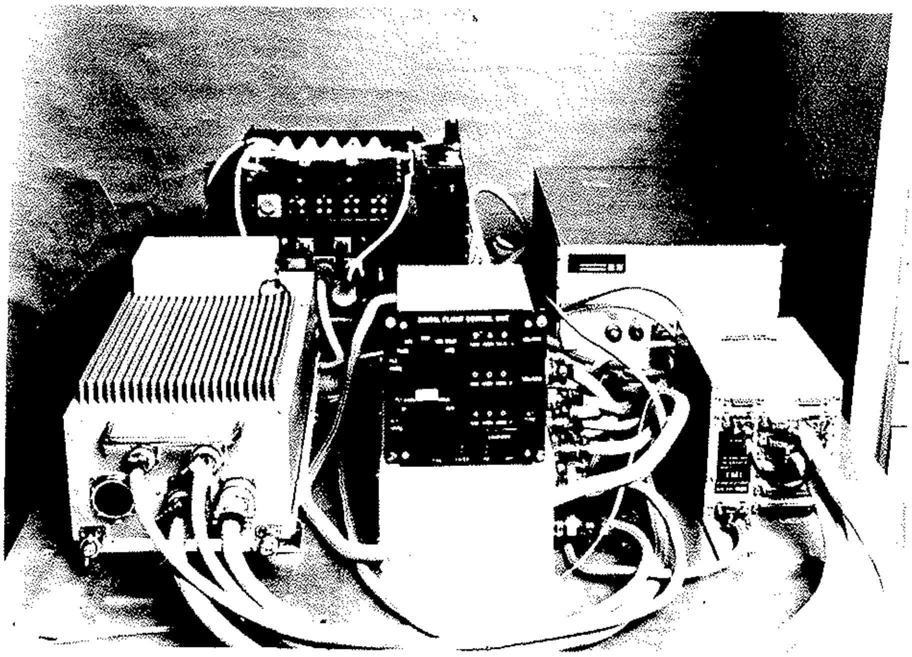


Figure 12:

Mini pallet with computer (front, left) sensorbox (rear, right) and control unit (front, middle). The other boxes represent telemetry equipment.

10. Summary

The paper described an experimental digital control system for helicopter applications.

The system provides an integrated solution for stabilisation, autopilot, air data computation and strap down computation. Realisation of the system was made using a double processor computer.

The control system and the sensors are selfmonitored, providing a fail safe capability for one channel. It may also be used in redundant applications.
Successful flight tests have been conducted.