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PROGRESS IN DIGITAL FLIGHT CONTROL PROJECT

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Summary

The Delft University of Technology Digital Flight Control project is aimed at developing a vehicle for research in the area of measurement and control of digitally controlled aircraft. Basic components of the closed-loop control system are a de Havilland DHC-2 "Beaver" laboratory aircraft, a digital flight computer and a set of electro-hydraulic and electric servo's.

First flight of the basic open-loop configuration is scheduled for spring 1983. The paper deals with the development and functional testing of the various components involved in these tests. Furthermore, current development and installation of components for closed-loop flight testing is treated.

Progress in Digital Flight control Project

Contents

1. Introduction

In the present generation of transport aircraft, a marked tendency towards application of digital data processing techniques can be discerned. Although the application of digital processors is particularly apparent in instrument display and instrumentation philosophy, the advance of digital technology will also have its impact in flight control engineering.

This trend prompted the initiation of the Digital Flight Control (DFC) project, aimed at the development of a digital flight control-system for the experimental aircraft of Delft University of Technology (DUT). Since introduction of digital tehnology in an in-flight environment and practical application of closed-loop flight control systems would be novel to the members of the DFC-group, it was decided to adopt a stepwise approach.

The first stage of the project will be aimed primarily at installing the relevant electronic hardware components and their validation in actual flight.

In this preliminary stage, indicated as the "pilot project", control of the aircraft will still be exercised by the pilot, and the automatic flight control system's authority is limited to a visual display of the desired flight control inputs (flight director system).

In the second stage, several actuators and their supporting systems will be installed in the experimental aircraft. In this installation, the original mechanical control runs will be retained, and coupling between the servo-systems installed and the control surfaces or engine control levers can manually be overridden by the pilot.

The first and second stages of the DFC-project are primarily aimed at gaining experience with the practical aspects of implementation of digital flight control systems. Such experience will then form the basis for further extension and redefinition of the project.

The present paper, which is reporting the status quo of the DFC-project, is organized as follows.

Chapter 2 deals with the initial basic aircraft configuration. A short description is given of the airframe and analogue flight control system currently installed.

Chapter 3 describes the extension towards the configuration as required for the installation of a digital flight control computer system. Included is a short description of the digital computer that will be employed in the initial stages of the DFC-project. This computer, a Rolm 1603, will be replaced in subsequent stages of the project. Replacement is due for 1985.

Digital flight controller software developed is treated in Chapter 4. The flight controller software was designed to ensure maximum flexibility for the application of alternative flight control laws. Software however is assembler-coded to minimize execution time.
Although, for the system envisaged, no particular emphasis is placed on system reliability, application in actual flight requires certain precautionary measures against the effects of failures. Chapter 5 gives a survey of switching logic and system monitoring facilities. Chapter 6 finally deals with the development and functional testing of the various components. Preflight testing is concluded with validation tests in a so-called "iron bird" set-up, where operational conditions for the complete digital control system configuration are simulated on a hybrid flight simulator installation.

2. Basic aircraft configuration

In the DFC-project a number of existing components will be used. Prominent among these is of course the experimental aircraft of Delft University, a De Havilland DHC-2 Beaver (see fig. 1). The aircraft is powered by a radial Pratt & Whitney Wasp Jr. piston engine with a maximum power of approximately 450 hp, driving a two bladed constant speed propellor, and a 3 kWatt 28 V DC generator. Primary control inputs consist of throttle setting, commanding the engine intake pressure, and engine speed setting, commanding the propeller's speed governor mechanism.

The basic airframe is furthermore equipped with the usual control runs for elevator, aileron and rudder control, and elevator trim and flap setting devices. Elevator, elevator trim and rudder are cable-operated, while aileron and flap control is exercised through a system of pusher and torquer rods. Electronic instruments and instrument displays installed feature, besides radio and navigational equipment, an analogue KFC-300 Flight Control System, manufactured by the King Radio Corporation of Olathe, Kansas. The King KFC-300 system used on the DHC-2 Beaver includes the following components: KDC-310 Flight Command Indicator, KCP-320 Flight Director Computer, KDC-380 Air Data Computer, KPI-553 Pictorial Navigation Indicator and KMC-340 Mode Controller (see fig. 2).

When fitted with auxilliary components, the system can also provide autopilot control. This is not the case in the DHC-2 Beaver.

The central component of the King system is the KCP-320 analogue Flight Director Computer. It receives inputs with respect to roll, pitch and heading attitudes from the vertical and directional gyros of the TARSYN gyro platform, and input with respect to flight altitude and rate of climb from the Air Data Computer. As well, localiser and glide slope beam deviations are fed in from the localiser and glideslope receivers.

The mode status of the system is input from the KMC-340 Mode Controller which also monitors sensor malfunctioning signals. Mode status is continuously displayed on the KAP-315 Mode Annunciator Panel. The Mode Controller panel provides for heading bug setting and seven separate flight director mode selections. The eight or "Go-around"-mode is selected by operating a switch installed on the throttle control lever. Furthermore, a system pre-flight test may be activated using a switch located on the Flight Command Indicator. Command bars are synchronized using a switch on the control column.

Using the inputs from the mode controller, sensors and pilot-operated switches, the KCP-320 determines roll and pitch commands through its hardware-installed control laws. In the KFC-300 systém many of the gains are scheduled with the indicated airspeed. In the Beaver however, the normal flight domain includes only the lower region of the scheduled airspeeds causing actually the lower limit to be maintained. As a consequence, these gains are all fixed at their value corresponding to the normal cruise speed of the Beaver, approximately 100 knots.

Roll and pitch command signals determined are sent for display to the KDC-310 Flight Command Indicator. Separate warning flags are installed on the KDC-310 to indicate sensor malfunctioning. Sensor failure signals are set by the Mode Controller.

3. Digital Flight Control System specification.

The first stage of the DFC-project is aimed at the validation in actual flight of the electronic hardware components of the proposed digital flight control system. To this end, the original analogue King flight control system will be copied by an equivalent digital control system. A Rolm 1603 computer is programmed to perform the functions of the King KCP-320 Flight Director computer. The Rolm 1603 is placed at our disposal by the National Aerospace Laboratory (NLR). Ample practical experience has been gained with this computer in off-line programming and testing. A more permanent installation of one or more larger digital computers will be considered after preliminary on-line flight testing.

The Rolm 1603 computer configuration contains the following components:

- Central Processing Unit with Extended Arithmetic Unit (EAU)
- 16 k, 16 bit words, core memory, cycle time of 1.2 microseconds
- five I/O Interface cards:
    - Combination I/O Interface, with Real Time Clock, model no 3300
    - 16 bit parallel I/O buffer, model no 3450
    - ADC-card with 16 channel multiplexer, model no 3656
    - DAC-card with 3 DAC's model 3650A
    - SDC-card with 8 channel multiplexer, DDC modelno 6325
- Control panel and power supply 115V 400Hz.

To perform the flight director computer function, the Rolm 1603 will be interfaced with the aircraft sensors, mode controller and pilot control inputs (interface I, see fig. 3). This interface scales the electrical signals generated by the Air Data Computer, converts the aircraft heading error signal to a synchro-signal, and transforms discrete dc input signals to transistor-transistor logic (TTL). Also, anti aliasing filters are installed in the interface unit.Table 1 gives an inventory. Computer output is converted to appropriate electrical signals for the pitch and roll command bars, the annunciator panel and a separate data logging system (interface II, see table 2). Note that interfaces I and II do not replace the computer's own interface cards.
The input to the digital flight director control laws will be supplied by the sensors currently installed for the equivalent analogue system. Observed variables will however be augmented with accellerometers for longitudinal and vertical specific force [illegible], barometric sensors and angular rate gyro's. The latter set of sensors is installed, together with the digital computer and its interfaces, on a detachable pallet assembly. Sensor signals furthermore include

displacement of aileron and elevator control surfaces. All sensor signals, and a set of system status discretes, will be recorded in digital format on a magnetic tape-unit. This unit also is installed, together with its interface (interface III) on the flight computer pallet assembly.
The entire assembly can be quickly disconnected and removed from the aircraft. Connection to standard aircraft instruments is through a single multi-contact plug. Power supply is received from the aircraft's 28VDC power generator system, and is adapted to 115VAC 400Hz by a static inverter mounted on the rack. Thus, the pallet assembly forms a self-contained unit for laboratory and in- flight test purposes. Modification of the basic aircraft configuration is restricted to the installation of separate connections on the existing power supply system, flight director sensors, Flight Command Indicator and Mode Controller. Also, connections are to be established to the "SYNC"-(synchronize) and "Go-around"-switches.
The second stage of the DFC-project requires a further and more elaborate modification of the existing aircraft systems. A major requirement is the installation of a hydraulic pump and power pack to supply the hydraulic pressure for operating the electro-hydraulic servo's. The system is essentially analogous to an equivalent system, installed to run a program aimed at non-stationary flight testing measurement techniques in 1976 (see fig. 4). Main difference is the application of a set of four servo's that are developed by DUT's Department for Mechanical Engineering (see fig. 5). These servo's were designed according to the hydro-static bearing principle, virtually eleminating dead zones and reversal shock. Hydraulic pressure is controlled through electrically operated valves. Separate servo control loops were developed to establish dynamic feedback, using the servo's plunger displacement and differential pressure sensors (see chapter 6). Input to the control servos can be generated either by the digital flight computer, connected to the servo through an ARINC-bus, or by the pilot, using a side-arm controller and/or trim potentiometers. Thus, the hydraulic servo-system can be tested under open-loop flight conditions before automatic flight is attempted.
Engine manifold pressure and propeller RPM will be regulated by the digital processor through direct current motors. These servos will be connected to the control lever rod system through cog-wheel mechanisms with limited displacement. Separate hardware electronic control loops are envisaged to establish positional control.

4. Digital Flight Controller software

To maintain flexibility in programming the control tasks designated, the flight control computer software has a modular structure. Modular programming is based on a strict functional separation of program tasks and subsequent implementation in subprogram parts or modules. In a suitably chosen modular structure, redefinition or extension of control tasks is implemented simply by exchanging the relevant module(s), thus limiting the amount of programming effort and enhancing program flexibility.

The digital flight controller program package is Assembler-coded and contains five main modules, corresponding to the main program functions (see fig. 6):

1. Master Routine (MSTR), submodules PROCON and START
2. Data Input Routine (DIR)
3. Mode Control Routine (MCR)
4. Flight Command Routine (FCR)
5. Data Output Routine (DOR)

In the program control routine (PROCON), which is part of the Master Routine, execution time can be allocated to the separate software modules. PROCON initiates each routine at the correct instant in time, and verifies the time-schedule. Cycle control on a time-basis is enabled by the Real Time Clock (RTC), which is part of the combination I/O Interface. The interrupt sequence, generated by the Real Time Clock is used as a clock-pulse counter to register time-base.

In addition to the Program Control Routine, the Master Routine includes an initialization-routine START, which initialises the complete software program, the Real Time Clock and the input devices. START is executed at the start of each flight or in case of recovery after system shut-down as a result of for instance power failure.

The Data Input Routine (DIR) reads appropriate input data, and converts these data for further processing by subsequent modules. Binary integer data is converted to floating point values, equivalent to the input voltages representing for instance attitude angles or accelerations. The floating point values are calibrated subsequently to obtain physical quantities. Calibrated input data is rearranged in shared memory locations, accessible to all other program modules.

The Mode Control Routine (MCR) is scheduled to activate the correct Flight Director Mode and to control mode-transfer on the basis of discrete input from the Mode Selection Panel. Furthermore, MCR combines the discrete output for the Mode Annunciator and Flight Command Display Panels. However the Mode Control Routine has not been implemented as yet. The tasks to be executed by this module are currently performed partly by the hardware Mode Controller, and partly by the next module, the Flight Command Routine. The Data Input Routine reads the Mode Annunciator logic information from the analogue Mode Controller. Status information is then used by the Flight Command Routine to activate the relevant flight control law.

Apart from the logic operations which adapt the Flight Command software to the KFC-300 system, the Flight Command Routine contains the actual control laws, which provide flight command signals for the flight director display. Calculated output signals are arranged in an output vector, accessible to the Data Output Routine (DOR).

The Data Output Routine outputs the command signals to the display. Command signals are calibrated to their proper equivalent voltages, and floating point values are transformed to binary integer output for the digital-analogue converters.

Although floating point arithmetic algorithms were available in the Rolm floating point interpreter, the required cycle-time of the complete software necessitated development of more efficient and faster floating point arithmetic algorithms. These newly developed floating point algorithms, based on the Extended Arithmetic Unit (EAU), proved to be an order of five times faster than the equivalent procedures of the Rolm floating point interpreter. The newly developed floating point instruction set processes 32 bit words(mantissa: 24 bits).

Execution times for floating point computations using this program package are:

floating point addition	0.41 msec
floating point subtraction	0.42 msec
floating point multiplication	0.39 msec
floating point division	1.65 msec

Cycle time for the entire digital flight director software program was defined to be 50 msec. Within one cycle, the DIR, MCR, FCR and DOR routines are executed within fixed intervals in time. Execution time was divided between the modules on the basis of experimental results. Such results were obtained by inserting HALT-instructions at relevant points in the program, and checking module execution times using the clock-pulsecounter. Available execution time was subdivided as follows:

DIR	14 msec
MCR	10 msec
FCR	20 msec (max)
DOR	6 msec
program cycle	50 msec

Note that, although the Mode Control Routine is not executable as yet, execution time has already been reserved for future implementation. At present, the MCR simply consists of a waiting loop consuming 10 msec of the cycle time.

The software as developed for the digital flight director computer is stored in memory locations 0 up to and including 4288 (decimal). However, required memory space amounts to 2828 locations (decimal) only. At several postitions memory-space is intentionally left blank to allow extension of modules without modifying the existing software in terms of memory locations.

Apart from the program, its modules, and the floating point package, several Rolm utility library routines were employed, i.e. floating point interpreter, debugger and binary loader. Of 16383 memory locations available, only 6913 are used at the moment, leaving a total of 9470 locations available for further extension.

5. Flight safety considerations

Reliability demands for flight-critical control systems are rather severe. For such systems, control system development would have a heavy bias towards redundancy management techniques. In the DFC-project, manpower and funds available are however essentially limited, necessitating a restriction to non-flight-critical controller design concepts. The system configuration employed consists of a single-channel digital control system, with system back-up provided by the original aircraft configuration.
For the digital flight director phase of the DFC-project, system installation basically consists of shunting the components of the pallet assembly with the aircraft systems (see fig. 7). Interconnections are added to, but not inserted in, the original aircraft circuitry. Thus analogue systems are fully retained operational as a back-up in case of digital system failure.
Analogue back-up is selected by the observer, through a switch located on the pallet's observer panel (Rolm/King switch, see fig. 7). The switch controls a set of single-pole-double-throw relays connecting flight director computer output with the relevant instrument displays and annunciators. Also, digital control system components can be completely isolated from the basic aircraft configuration by de-activating a set of "on/off" relays, using a single switch on the observer's panel (isolate/measure-switch). By operating the switch all input to the digital flight computer assembly is automatically disconnected. The latter switch is coupled with the "Rolm/King" switch to prevent activating the isolated digital system. Switch position can be monitored through a set of annunciator lights. The relay box will be placed on the rear bulkhead.
In the analogue King KFC-300 flight director equipment, sensor failure signals, generated by the TARSYN and Air Data Computer built-in-test equipment, are displayed on the Flight Command Indicator. This feature will be retained in the digital flight director installation. Modes using such incorrect sensor signals are automatically disengaged and command bars are retracted. Failure detection of the digital flight director computer is limited primarily to a software "Power Failure Monitor" routine.
An interrupt signal is generated when power supply decreases below a dangerous level. The program is then discontinued, and 500 microsec are allocated for power failure control action. Power failure control action consists of retracting the flight command bars, extinguishing all annunciator lights and lighting the "computer invalid" signal. Furthermore the starting adress of the START-routine is placed in memory location 0, enabling automatic restart of the program after power failure correction. Finally, program execution is

discontinued through a HALT-instuction.
Automatic restart is possible only in the "DISABLE" position of the "panel enable/disable switch, located on the computer control panel. Manual restart in the "enable" position is through operating the "continue" switch on the control panel, causing a "jump"-instruction to the starting adress of the START-routine to be executed.
When functioning normally, the digital computer produces a pulse at the end of each computation cycle. The sequence of pulses is monitored by a "heartbeat detector" in the interface unit. A "computer invalid" signal is set upon interrupting this sequence of pulses. Pulses are generated by the software program and thus provide limited monitoring facilities for proper program functioning.
Pre-flight test facilities are provided by a separate software module, which is part of the Flight Command Routine. Activating the "pre-flight test" button, located on the Flight Command Indicator, results in a climbing right-hand turn (10° pitch and 10° bank angle) to be displayed on the artificial horizon. Command bars will move to correspond to horizon position, all warning flags are displayed, and all annunciator lights are set. Normal program execution is resumed after releasing the "pre-flight test" button.
Similar arrangements in both hard- and software will be made for the second stage of the DFC-project involving flight tests of some autopilot modes (see fig. 7). Back-up and reconfiguration are provided by the human pilot, who can revert to the original system configuration at any time by a single manipulation. If necessary, digital control system shut-down can be completed by pilot or observer as described before.
Main difference between the digital flight director and digital autopilot aircraft configurations is the semi-permanent installation of electrical and electro-hydraulic servos. For the electro-hydraulic servos (see fig. 8), an hydraulic circuit is envisaged, driven by a pump that is linked mechanically to the engine. Hydraulic system operation is enabled by a fused main switch. The system will be monitored for proper functioning of the selector valve, minimum oil pressure and compensator volume, each item controlling a switch in a series of three. During pressure build-up, when first starting the system, the latter two switches are overridden by a manually operated "override" switch. Further logic includes upper- and lower-limit switches and three manually operated cut-out switches, located on the control wheels and on a separate side-arm controller. All switches, with the exception of the "limit" switches, de-activate the entire electrical and hydraulic servo-system circuitry. This also involves the electro-magnetic clutches, coupling each servo to its relevant mechanical control run. Magnetic clutches are further decoupled by the "limit"

and a set of switches ensuring proper positioning of the clutches with respect to the existing control system.

Hydraulic pressure, oil temperature and "servo-arm" lights are displayed on an overhead control panel. The panel contains also the "main", "selector valve", "override" and "servo-arm" switches.

Both electro-hydraulic and electrical servo's may be overridden by manual force, exerted by the pilot. For the electro-hydraulic servo's, shear-pins of suitably chosen strength will be installed, whereas the electrical servo's will be coupled using a friction mechanism. Servo-systems installed on the engine control levers will have limited authority. Servo-system installation is still under development.

6. System development and testing

As a preliminary to closed-loop flight control, digital flight control system components are to be validated in actual flight in an open-loop configuration. Applying the digital control system as a flight director computer, system performance is easily verified when using responses from the commercial equipment currently installed in the aircraft as a reference. Thus an excellent system check is provided by implementing King analogue flight director control laws in the digital flight control computer.

Transfer functions for the various King Flight Director modes were determined using analytical block diagrams and wiring diagrams from system documentation. Many of the gains in the King Flight Director Computer are strappable, so that they vary on different adaptor boards used in different models of aircraft.

Also , values of limiting functions may vary. Experimental tests were therefore run on the Beaver-King system.

Frequency responses of the Beaver-King system were obtained by using a variable phase wave function generator as an input to the King KTS-146 Flight Line Tester. This tester is designed to troubleshoot problems in the KFC-300 Flight Control System, simulating the signals from the vertical and directional gyros, air data computer and localiser- and glideslope-receiver. The function generator was used to input varying frequencies for each mode. Flight command output signal magnitude and phase-lag were recorded, providing Bode-diagrams of the system.

Static gains and time constants were furthermore identified applying step inputs. Data obtained were verified in a non-linear aircraft simulation program.

Using a discretized version of the resulting flight director control laws, a Flight Command Routine for the flight control program package was constructed and implemented in the Rolm 1603. At this stage also the interfaces I and II had been completed, and a series of static and dynamic tests could be performed.

The basic experimental set-up consisted of the following components:

- Rolm 1603 digital computer
- Interface Units I and II
- Paper-tape reader
- Teletype
- Static Inverter
- Laboratory power supply ([illegible])
- Testing console with "Annunciator lights" panel

The testing console's function is comparable to the [illegible] of the [illegible]

Flight Line Tester in the flight control law identification process described above. Using the Testing Console, input signals may be generated, respresenting analogue, synchro and discrete input from the sensors, mode controller and cockpit instrumentation. Flight Control Assembly output was displayed on voltmeters, representing the bars of the Flight Command Indicator, and on "bars retract" and "computer invalid" lights, installed on the Testing Console. A separate "Annunciator lights II" panel displayed annunciator signals.
During static open-loop bench-tests of the digital flight control assembly, simulated flight conditions could be obtained using the Testing Console input. Steady state response of the digital flight director system was checked, both by printing relevant data stored in the digital computer, and by measuring digital flight control system output. The testing method ensured verification of the complete assembly, including input and output interfaces. A number of small errors were detected in this way (see table 4), which had resulted primarily from incompleteness or ambiguity in system specification. Testing of all program functions proved to be a laborious process, underscoring the need for specially developed test-software for future development. Proper documentation was a major asset in limiting development and verification effort.

Response characteristics of the digital flight control system assembly were determined during dynamic open-loop bench-tests. Input was generated by a block-pulse generator, a frequency response analyser creating sinus-input (see fig 10). Output was recorded on a dual-trace recorder and a two-axis plotter, and was compared to theoretical time and frequency responses of the flight director control law transfer functions. No appreciable discrepancies were encountered.
Final tests prior to actual flight consist of verification of the closed loop performance in a so-called "iron bird" configuration. The digital flight control computer assembly, including the data-logging assembly, was coupled (Interface IV) to the flight simulation hybrid computer and flight simulator cockpit displays (see fig. 11). Acceptance tests are now being performed, and involve simulated flight throughout the flight envelope. For aircraft simulation a set of linear aircraft models is employed, representing the aircraft for some characteristic reference conditions. Linear(-ized) aircraft models are used to conserve on simulation execution time, thus preserving space for the software implementation of mode controller and sensor- and servo-system models. Although this is not a requirement for the "pilot project", such sensor- and servo models are scheduled to be included in the "automatic flight control system"-iron bird tests, where the same flight simulation software will be applied.
Sensor system model parameter identification involved a series of static and

dynamic tests, performed on the Air Data Computer barometric sensor. Static tests revealed some sensitivity with respect to vertical accelerations. The effect on a closed-loop autopilot configuration is cuurently under investigation. Time-lags due to pipe-line friction and compressibility effects, and sensor non-linearities will be included in the Air Data Computer sensor simulation model. Theoretical analysis of gyroscope systems resulted in a mathematical model incorporating gyroscope dynamics. Gyroscope response characteristics will have effect on the closed-loop configuration only when considering large time-scales. A restricted model will be included in "autopilot" Iron Bird tests.

The DFC-autopilot configuration will include three or four electro-hydraulic servo-systems (see chapter 3). Linear mathematical models describing these systems were provided by the manufacturer, the Department for Mechanical Engineering of DUT. Servo control loops were developed for the elevator control servo, on the basis of a model describing servo, aerodynamic control surface hinge moments and control cable elasticity. Resulting control loops feature positional feedback and pressure feedforward, augmented with a low-frequency pressure feedback loop. This control law configuration ensures insensitivity for aerodynamic load, yielding elevator displacement proportional to the command input, and sufficient bandwidth (approx 7.6 rad/sec). Failure of the positional feedback loop is potentially hazardous and thus requires in-line monitoring. Other control loop failures do not impair flight safety. Control loops will be implemented in hardware electronic circuitry.

The elevator servo with its control was tested under laboratory conditions in a separate experimental set-up. Aerodynamic loads and cable elasticity were simulated using a second servo, controlled by an analogue computer. The control servo performed satisfactorily.

Further testing will require more elaborate mathematical modelling, or may be performed under actual flight conditions.

7. Concluding remarks.

The DFC-project has now advanced to the point where acceptance tests for the digital flight director system are performed under simulated conditions. From the experiences gained in the design and development phase some conclusions may be drawn:

1. The digital computer employed in the first phase of the project provides ample storage space for the digital flight director instruction set. However, execution time for the rather comprehensive flight control tasks already covers a major portion of the cycle time defined. Future implementation of more complicated control tasks therefore hinges on a redefinition of cycle time(s), or the availability of a faster, more powerful computer. Since redefinition of the cycle time may result in a much more complicated control law configuration, its beneficiary effect is deemed marginal. Both application of the DFC-system for educational purposes, and development towards more complicated functions advocate installation of a faster digital processor.
2. Bench-testing of the complete digital flight control system assembly revealed a number of small errors. Since design specifications will usually suffer to some extent from vagueness or ambiguity, some errors are prone to arise in any newly developed system or system component, and elaborate testing is mandatory. Since for future development mainly changes in flight control computer software are envisaged, implementation of automatic software testing routines would seem profitable. Acceptance tests under simulated operational conditions ("Iron Bird Testing") inspire confidence in total system configuration. Also, the iron-bird set-up may be employed to trouble-shoot problems arising in actual flight.

The digital flight director assembly will have its maiden flight may 1983. A qualitative flight evaluation program is currently being defined. Digital Flight Control System development will then proceed by installing and flight-testing the control-servo systsems. Premilinary flight tests will involve the open-loop situation, where the pilot exercises control of the aircraft through a separate side-arm controller. This "fly by wire" flight test program is scheduled to commence early 1985.

Variable	Transducer	Transformation	Polm interface
angle of pitch θ angle of roll φ referential voltage	Vertical gyro (TARSYN)	- - -	SDC chan.nr. 0 SDC chan.nr. 1 SDC
heading ψ referential voltage	Directional gyro (TARSYN)	- -	SDC chan.nr. 2
heading error $\Delta\psi$ referential voltage	Pictorial Navigation Indicator (KPI 552)	from AM a.c to synchro -	SDC CHAN.NR. 3 SDC
altitude deviation Δh or rate of ascent/descent $\dot{h}$	Air Data Computer (KDC 381)	scaled: 1/-0.691	ADC chan.nr. 0 scaled: 1/0.69
roll rate p pitch rate q yaw rate r	rate gyro's	-	ADC chan.nr. 1 ADC chan.nr. 2 ADC chan.nr. 3
Vertical gyro valid Directional gyro valid	Vertical gyro (TARSYN) Directional gyro (TARSYN)	(1="1"TTL=+5V) (0="0"TTL=oV) from discrete d.c. to TTL	PIB, DI 0 PIB, DI 1
Altitude valid	Air Data Comp. (KDC 381)	valid: "1" invalid: "0"	PIB, DI 2

iable	Transducer	Transformation	Polm Interface
ght Dir. switch Sel. switch . Hold switch	Mode Control Panel	from discrete d.c. to TTL momentary: "1" else: "0"	PIB DI 3 PIB DI 4 PIB DI 5
Around switch	throttle lever		PIB DI 6
t. trim switch	Mode Control Panel	from discrete d.c. to TTL trim up : 100 trim down: 001 neutral : 010	PIB DI 7,8,9
chronization NC) switch	Control Wheel	from discrete d.c. to TTL in : "1" out: "0"	PIB DI 10
flight-test ch	Flight Command Indicator		PIB DI 11
ght Dir. Ann. I Sel. Ann. I Hold. Ann. I Around Ann. I	Mode Control Panel	from discrete d.c. to TTL on : "1" off: "0"	PIB DI 12 PIB DI 13 PIB DI 14 PIB DI 15
trol signal (IN CLCK)	POB, DO8	–	PIB, IN CLCK control line

Table 1: Digital Flight Computer interface input signals.

Variable	Rolm Interface	Transformation	to:
Pitch command Roll command	DAC chan.nr. 0 DAC chan.nr. 1	scaled: 2/3 scaled: 2/3	Flight Command Indicator (KDI310)
Bars retract	POB, DO 0	from binary to discrete d.c. "0"=retract: ground "1"=aligned: open	Flight Command Indicator (KDI310)
Computer valid	POB, DO 1	from sequence of binaries to discrete d.c. 1 pulse per cycle=valid:+28V no pulse=invalid: ground	Flight Command Indicator (KDI310) & control panel
Flight Dir.Ann.II HOG Sel.Ann.II Alt.Hold Ann.II Go Around Ann.II	POB DO 2 POB DO 3 POB DO 4 POB DO 5	from binary to discrete d.c. "0"=on: ground "1"=off: open	Annunciator Paneld II
Program number	POB DO 6,7	-	Interface III
Control signal PIB (IN CLCK)	POB DO 8	-	PIB, IN CLCK control signal

Table 2: Digital Flight Director Computer interface output signals

able	Transducer	Transformation	DLS Channel	
			Analogue	Discrete
e of roll φ	TARSYN VG	3 wire synchro to d.c.	0	
e of pitch Θ	TARSYN VG	3 wire synchro to d.c.	1	
ing ϕ	TARSYN DG	3 wire synchro to d.c.	2	
ing error $\Delta\phi$	PNI (KPI 552)	a.c. to d.c.	3	
tude deviation Δh or of ascent $\dot{h}$	Air Data Computer (KDC 381)	d.c. scaled	4	
h command	Analogue (KPC-320) or Digital (Rolm 1603)	d.c. scaled	5	
command	Computer	d.c. scaled	6	
rate p	rate gyros (Smiths)	d.c. scaled	7	
h rate q			8	
rate r			9	
mic pressure q_c	pressure sensor	-	10	
ator displacement δ_e		d.c. scaled	11	
ron displacement δ_a		d.c. scaled	12	
ic pressure p_s	pressure sensor	d.c. scaled	13	
ific force A_x	Donner	d.c. scaled	14	
ific force A_z		d.c. scaled	15	
light-test switch	Flight Command Ind.			1
-switch	Control wheel			2

Variable	Transducer	Transformation	DLS Channel	
			Analogue	Disc
Computer Valid	Analogue or Digital Computer	- (valid="1")		3
Vertical trim down Vertical trim up	Mode Controller			4 5
Program select	Digital Computer	-		6
FD Ann. I HS Ann. I AH Ann. I GA Ann. I	Analogue Computer	- (valid="1")		8 9 10 11
FD Ann. II HS Ann. II AH Ann. II	Digital Computer			12 13 14
Tape speed select	DLS			15

Table 3: Data Logging System (DLS) interface.

Component verification

- Acceptance tests showed malfunctioning of the ADC-interface card. The card was replaced.

- Actual device-code of the SDC-interface card differed from documented device code. Software was adapted to accomodate the new code.

- Explicit program instructions did not prevent Parallel Input Buffer from generating interrupt signals. Error source could not be detected, and amendments were made to the software to circumvent the problem.

- A memory card was repaired after repetitive malfunctioning.

- Computer overheating problems were overcome by mounting a small electrical fan. Apparently, manufacturer data apply to computer surface temperature limits, not to environmental temperatures.

Assembly verification

- Cycle time was redistributed after the FCR-routine displayed excessive consumption of execution time when using Vertical Trim in the Altitude Hold mode.

- Improper documentation of the scaling process, performed on the altitude deviation sensor signal in interface I, caused program discrepancies. The error was corrected.

- The altitude deviation sensor signal had a variable offset, resulting from power supply interference. Proper grounding solved the problem.

- Software conversion from binary integer to floating point was modified after malfunctioning of the limit-value-test procedure was detected.

- Noise-level of the altitude time derivative sensor signal necessitated pre-filtering.

- Power failure tests revealed inadvertent activation of annunciator lights II during the manual restart procedure. Modifications have not been made in view of the seriousness of the error and the effort required.

- Roll angle feedback in the Wings Level mode exhibited reversed sign. The situation was corrected.

- A software error, resulting in incorrect gain scheduling of the Heading Select control law, was detected and corrected.

Table 1.

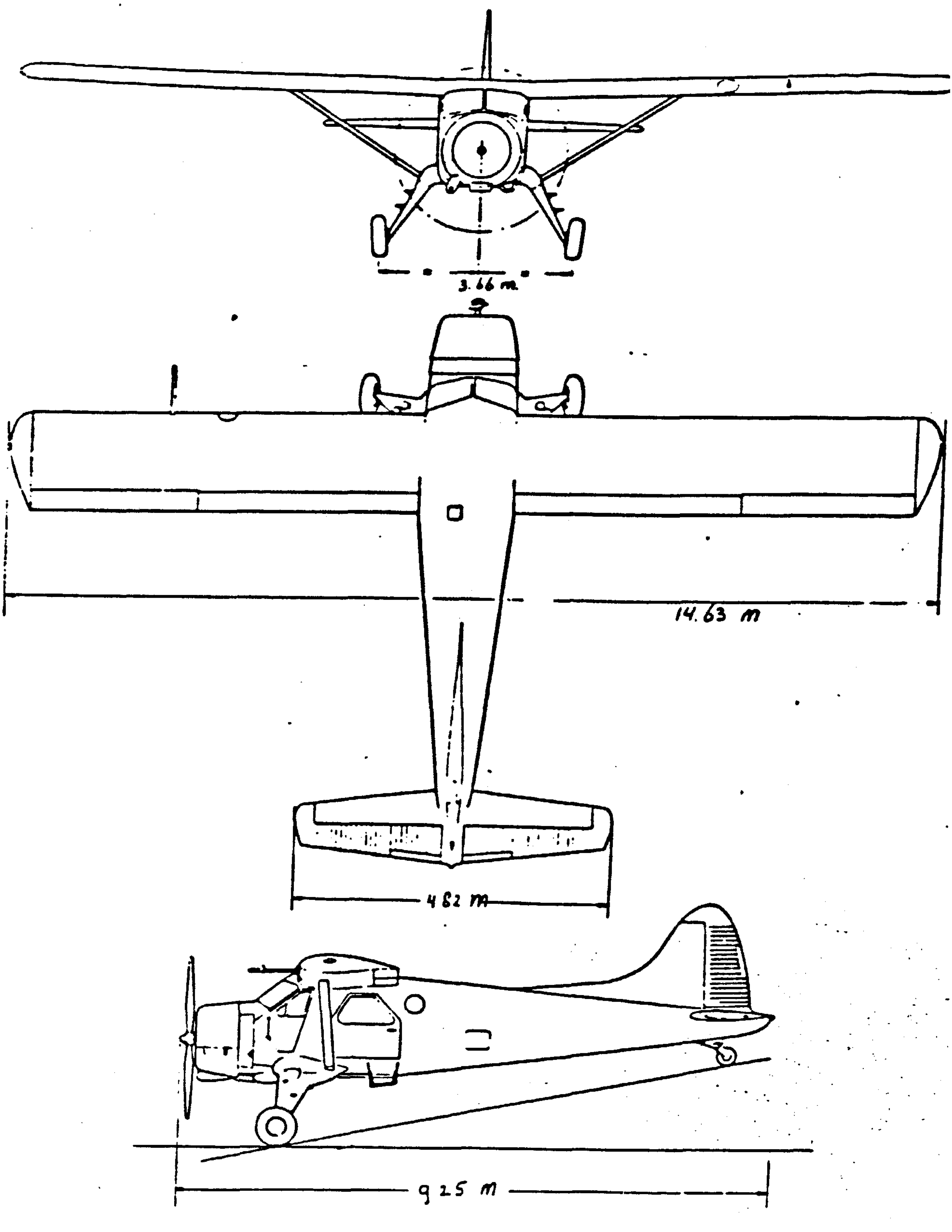

Fig.1: De Havilland DHC-2 "Beaver" experimental aircraft

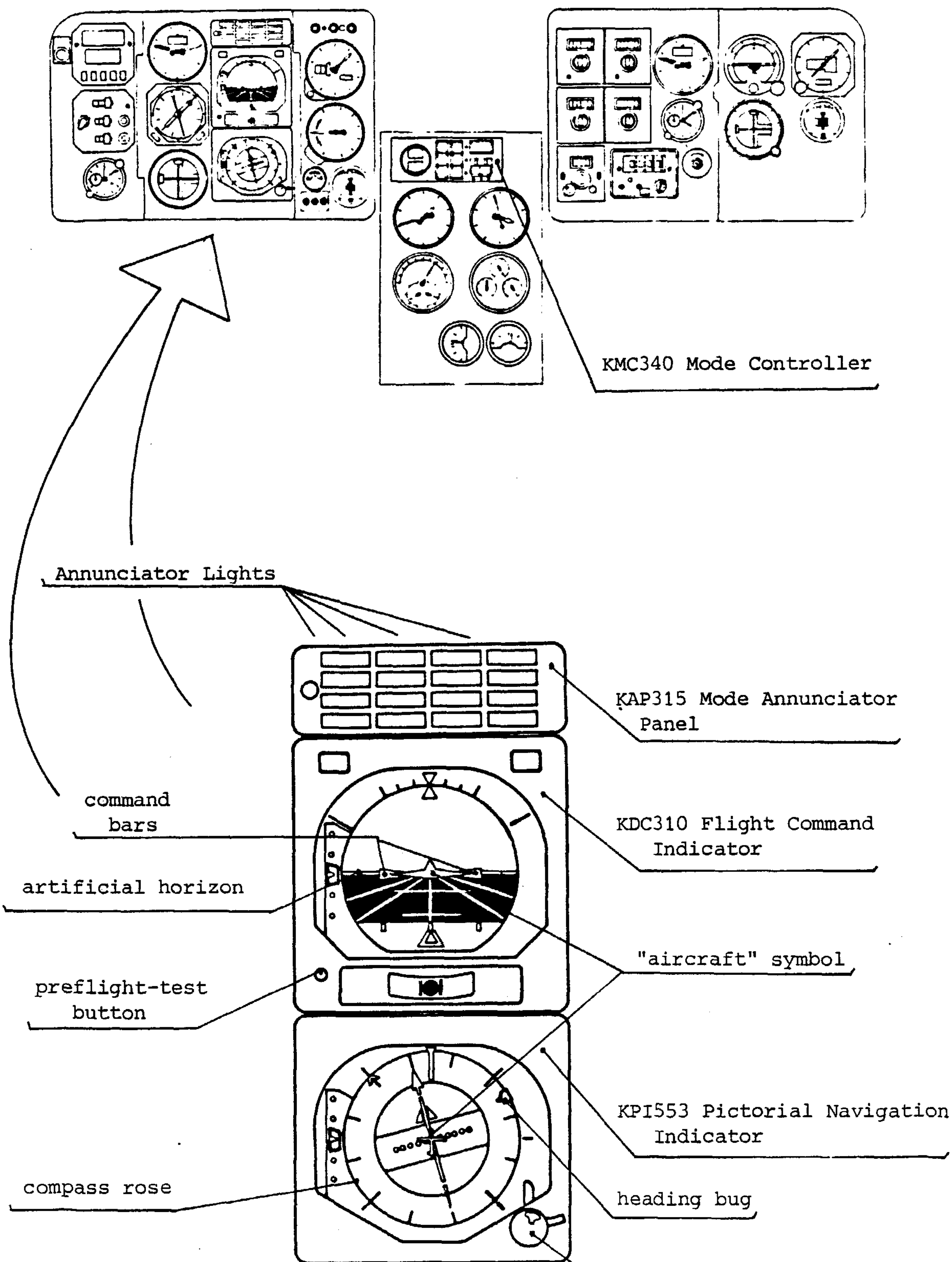

Fig.2: Experimental aircraft cockpit instrumentation

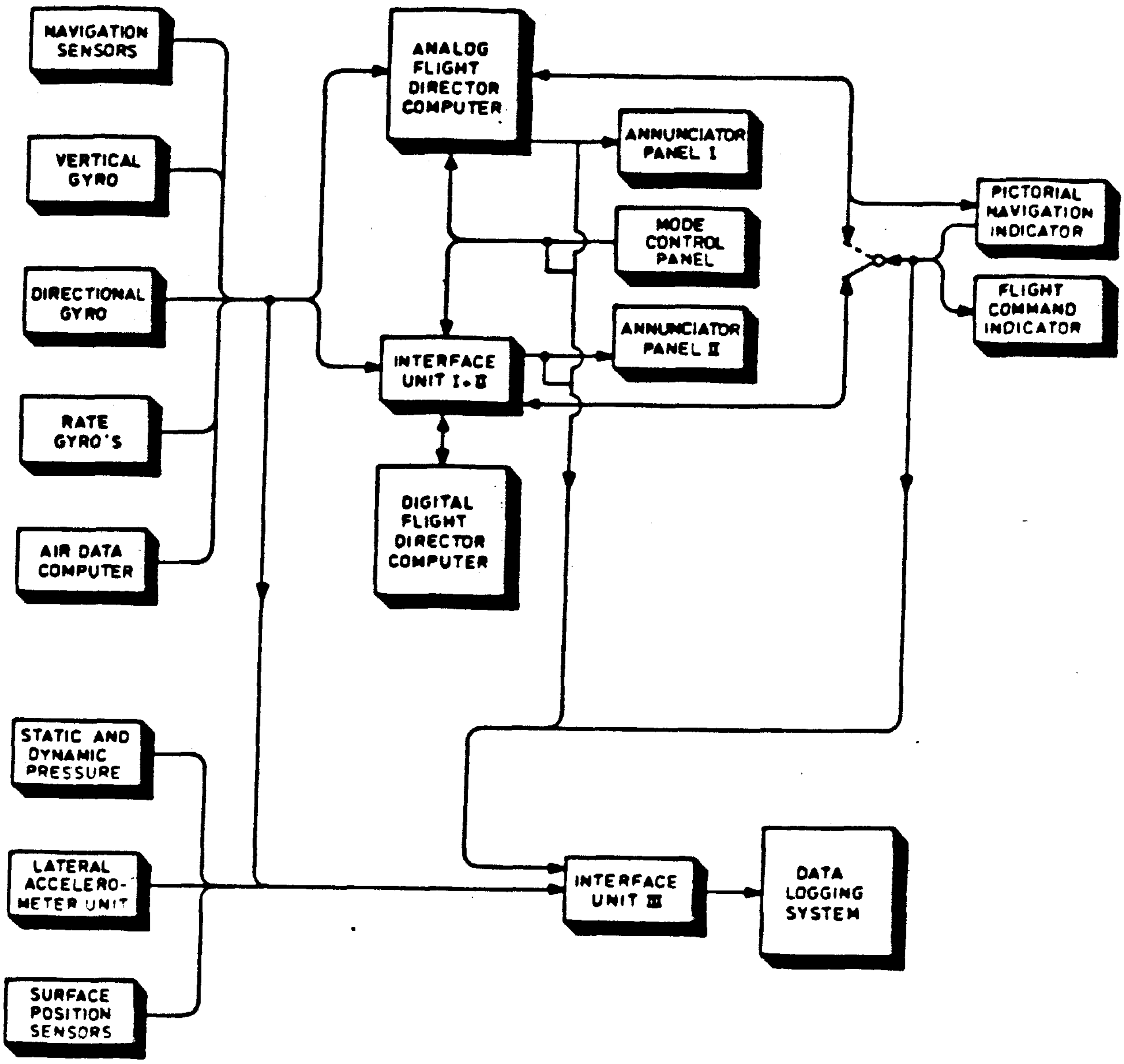

Fig.3: Digital Flight Director system

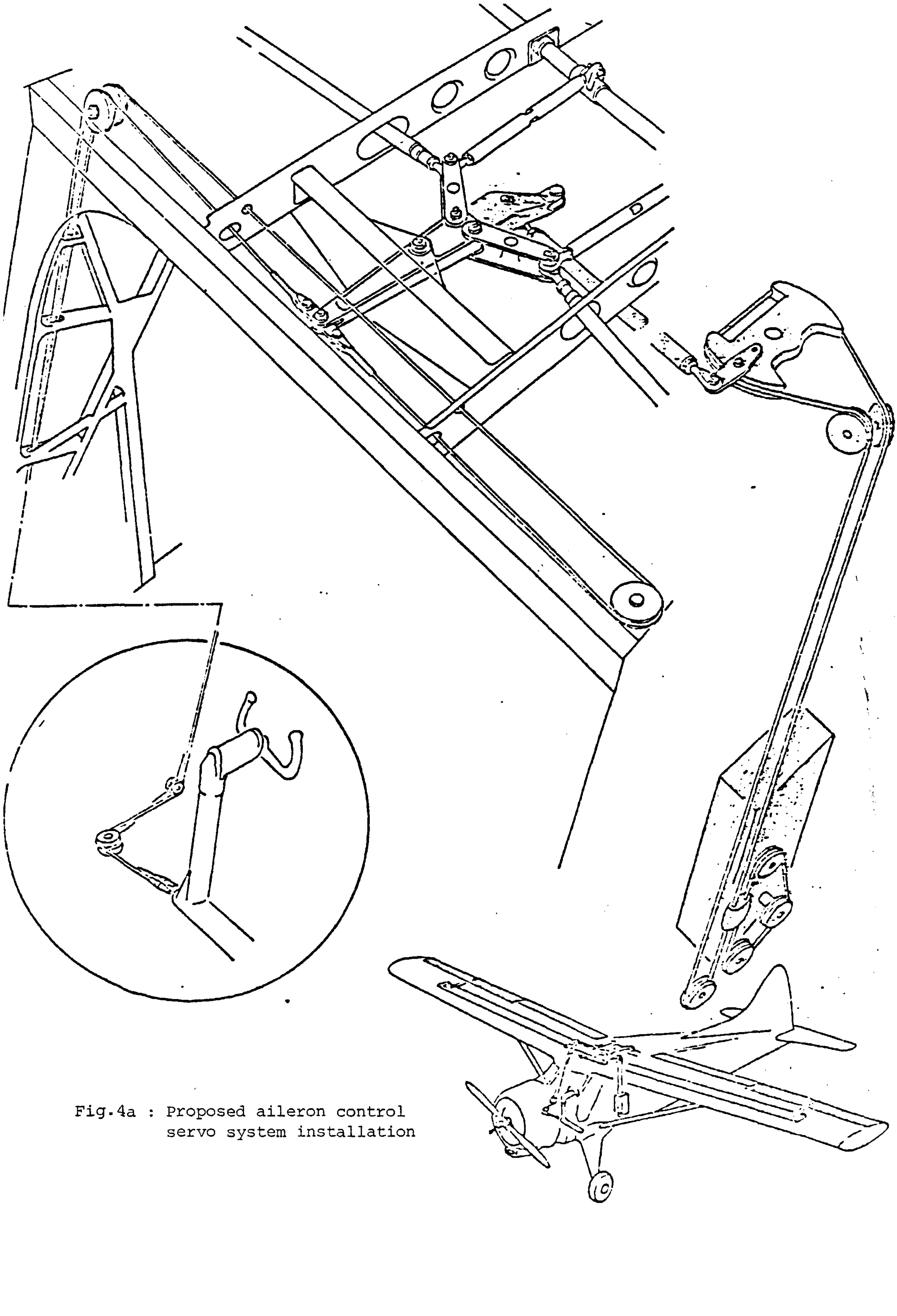

Fig.4a : Proposed aileron control
servo system installation

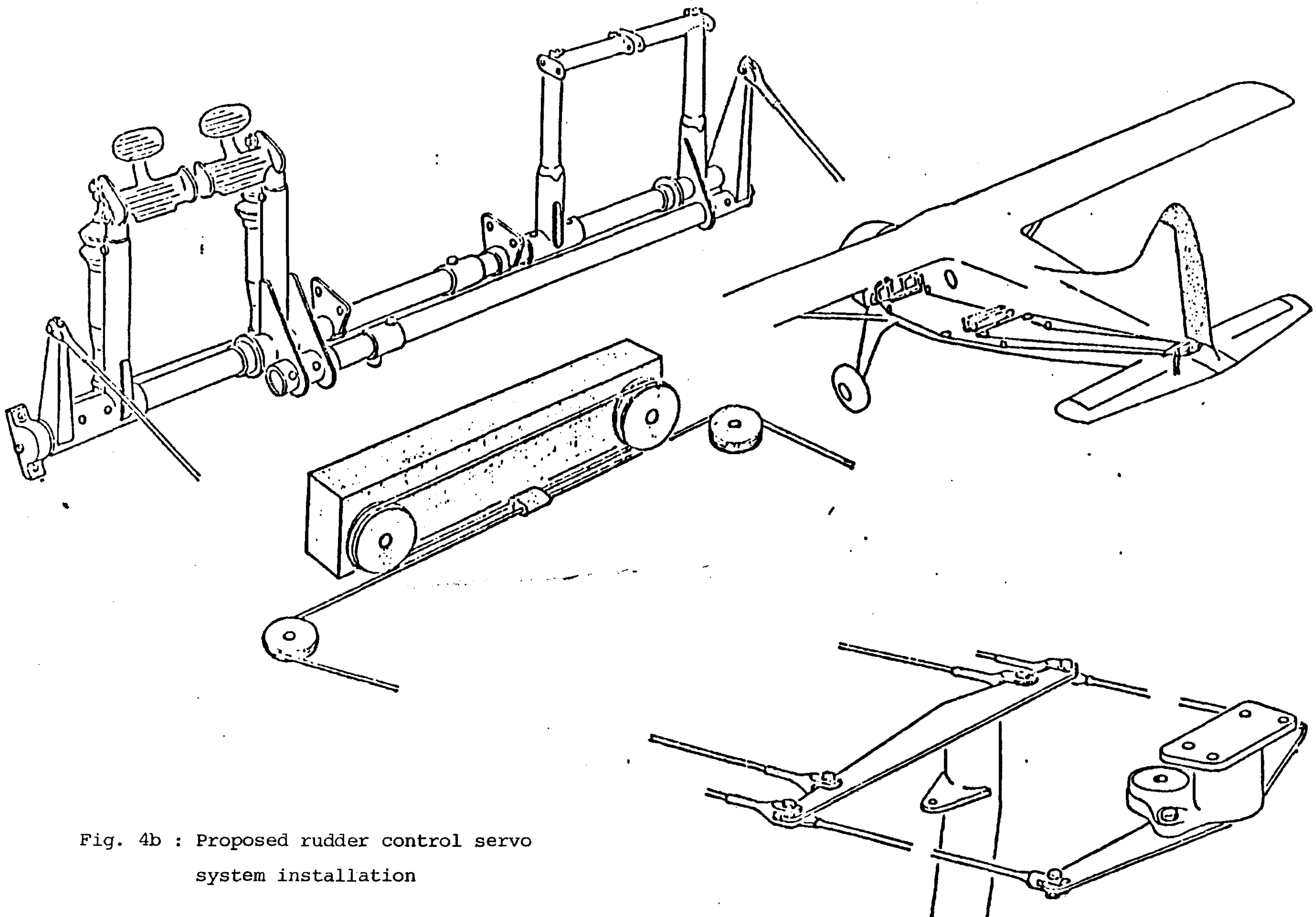

Fig. 4b : Proposed rudder control servo
system installation

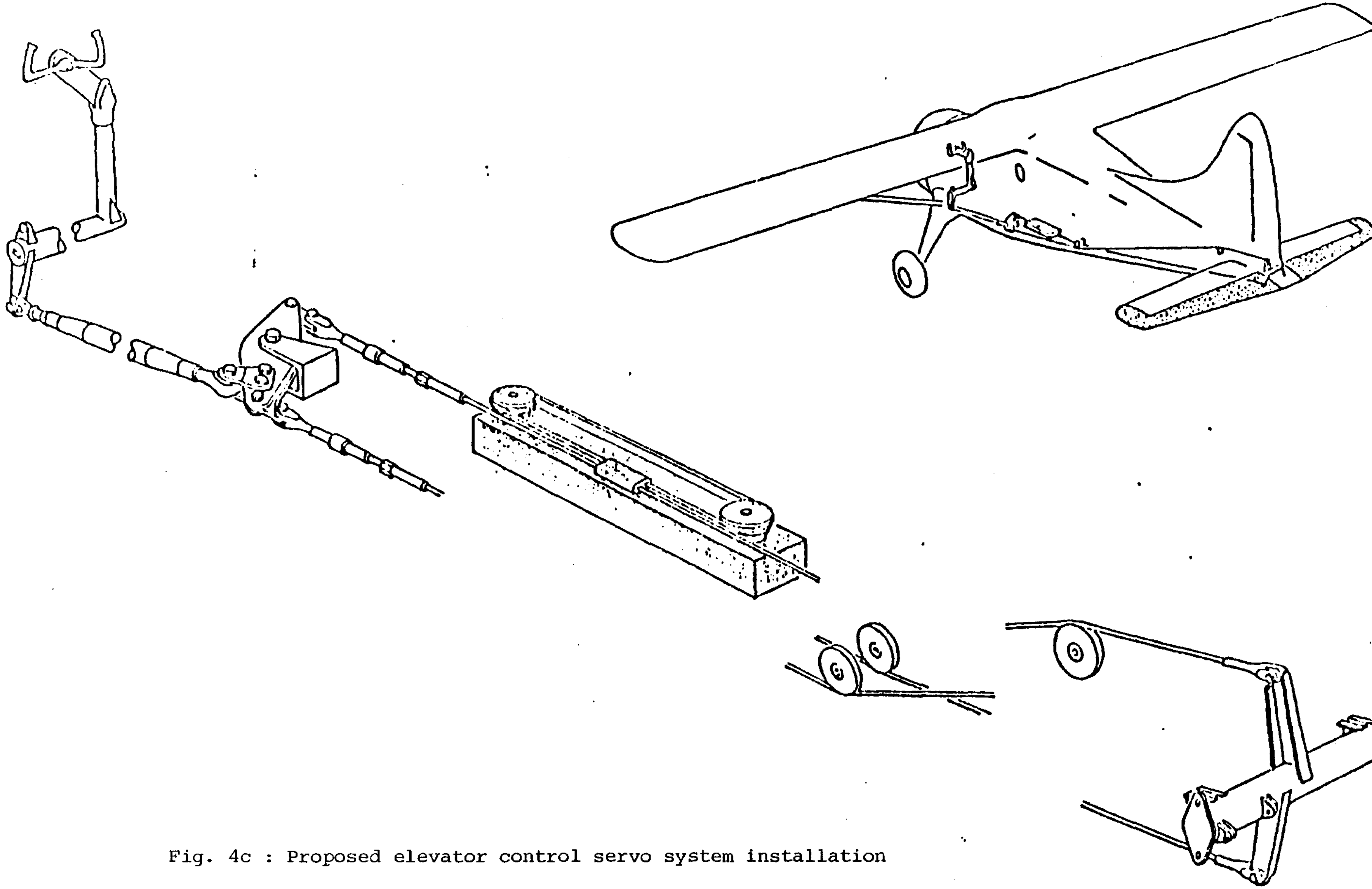

Fig. 4c : Proposed elevator control servo system installation

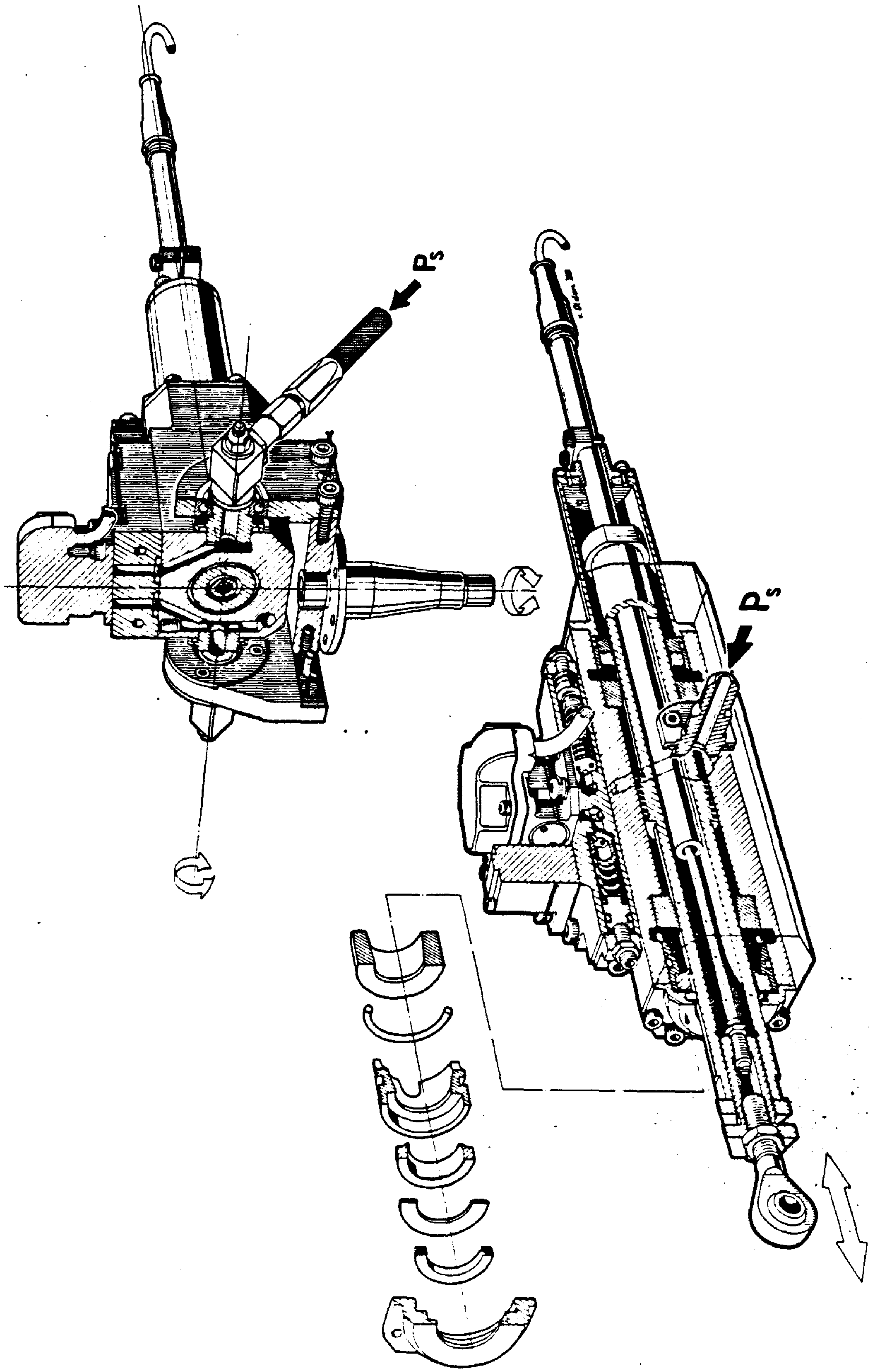

Fig. 5 : Electro-hydraulic actuator

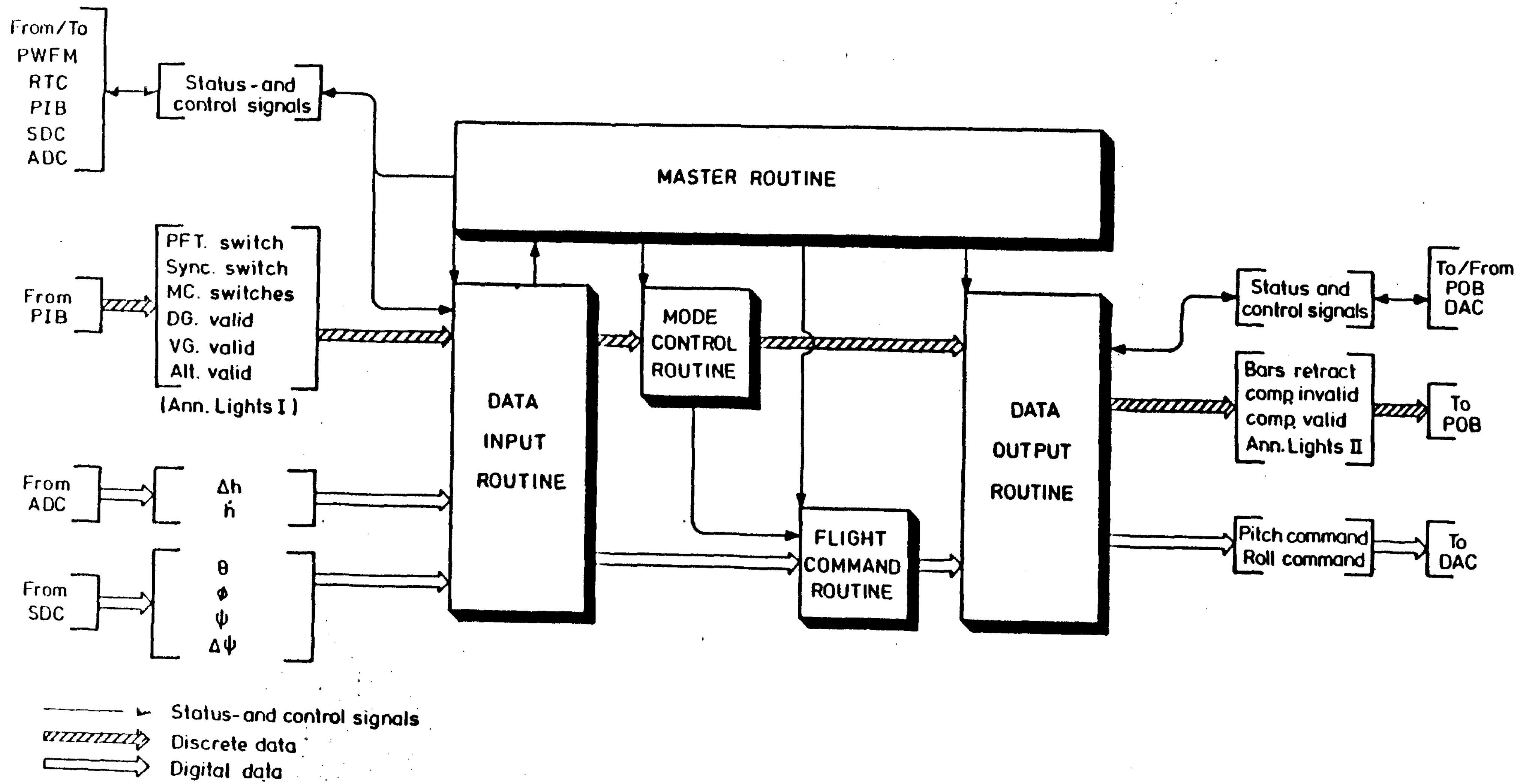

Fig.6 : Digital Flight Computer program package

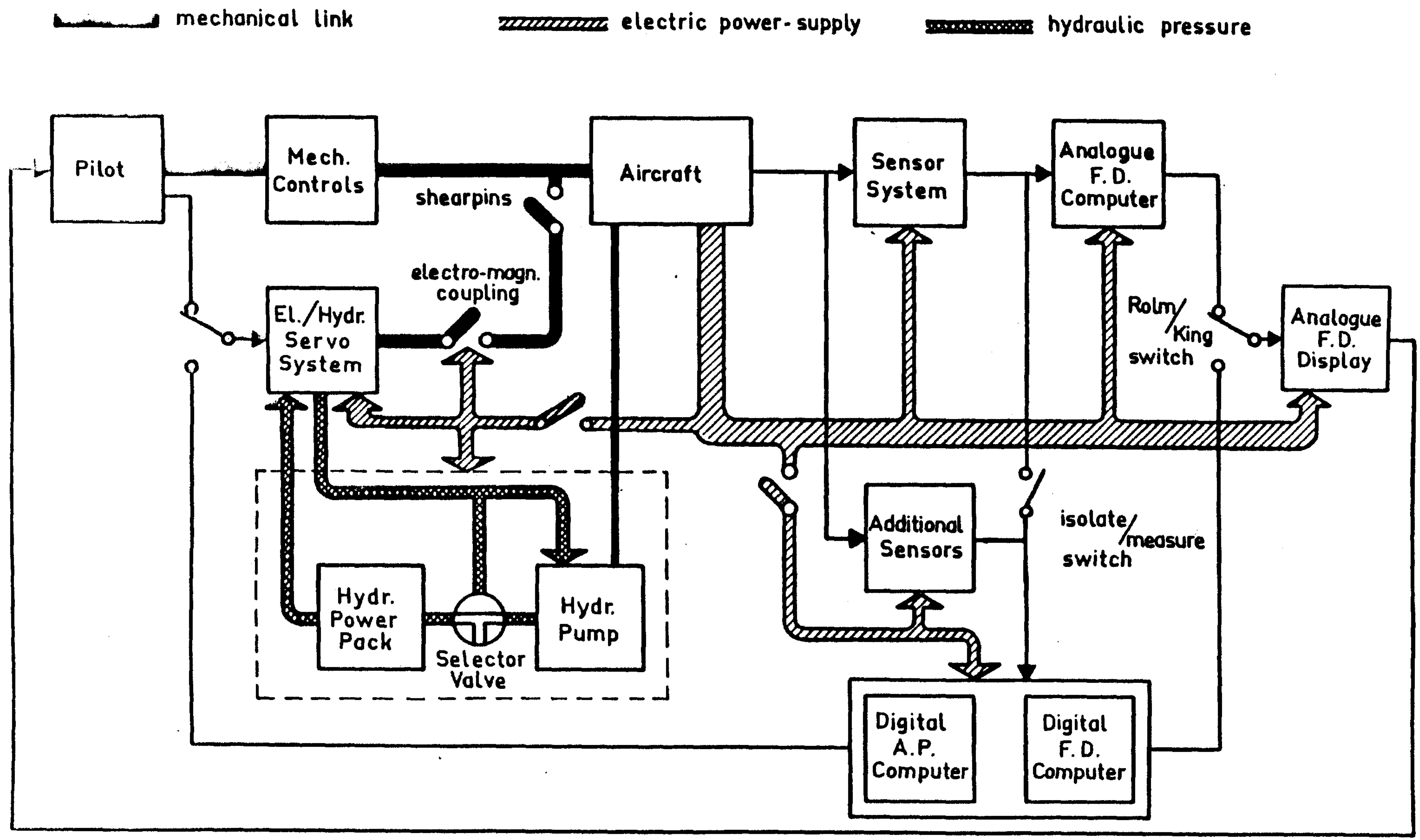

Fig.7 : Simplified diagram showing projected flight director/autopilot installation

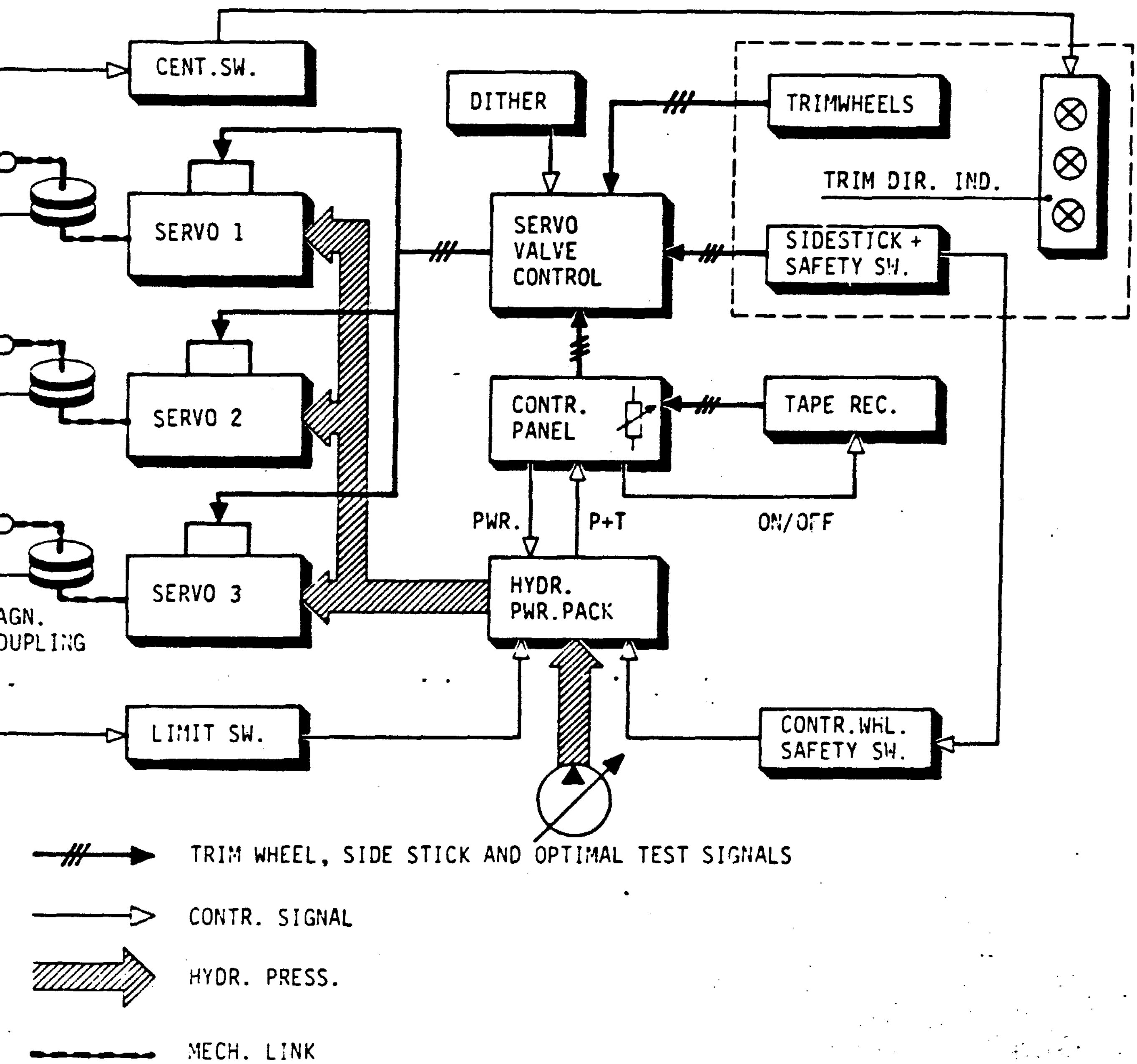

Fig.8. Servo-system installation in dynamic flight testing project.

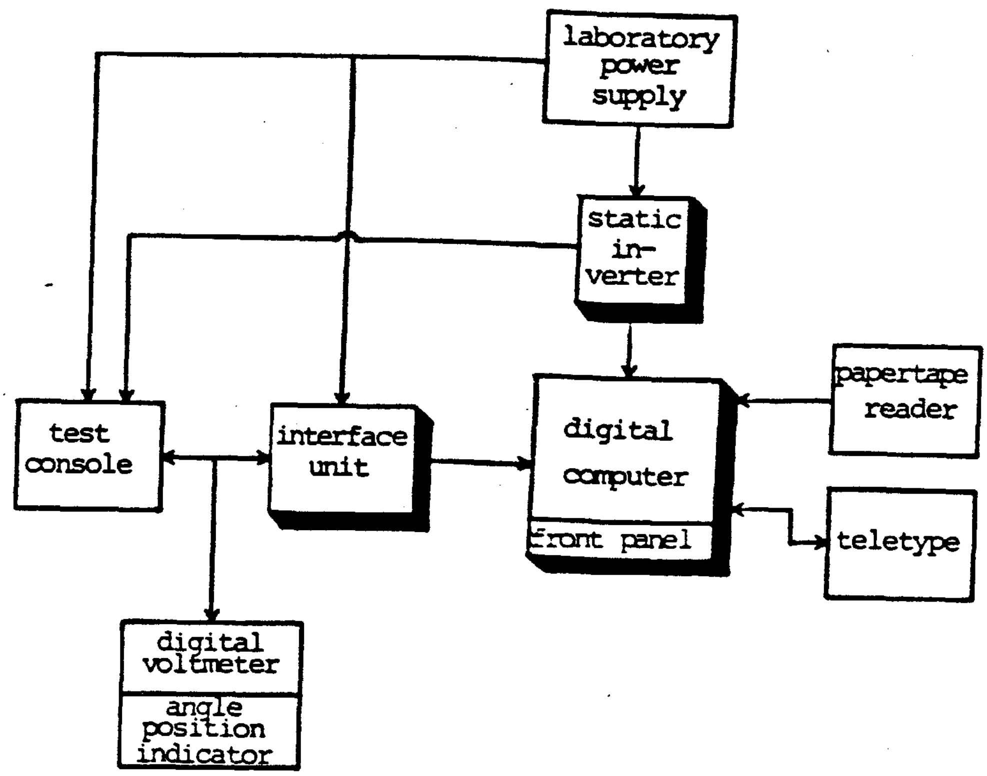

Fig.9 : Software verification experimental set-up (static bench-tests)

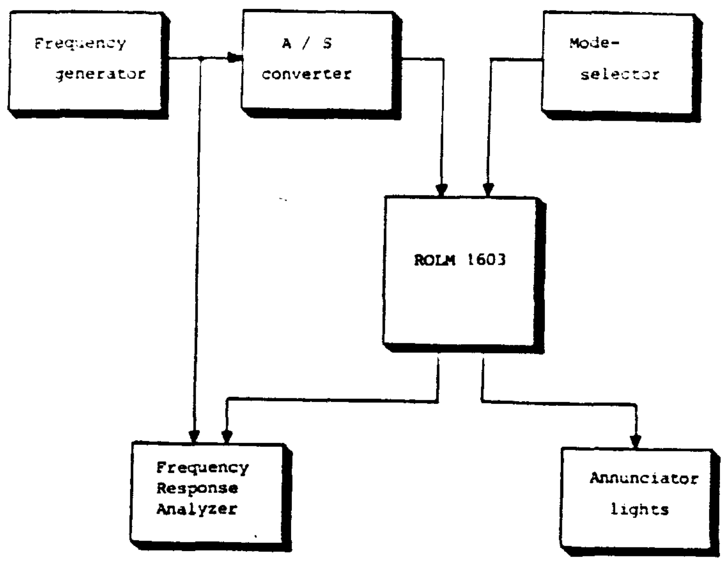

Fig.10a: Experimental set-up for determining frequency response characteristics (dynamic bench-tests)

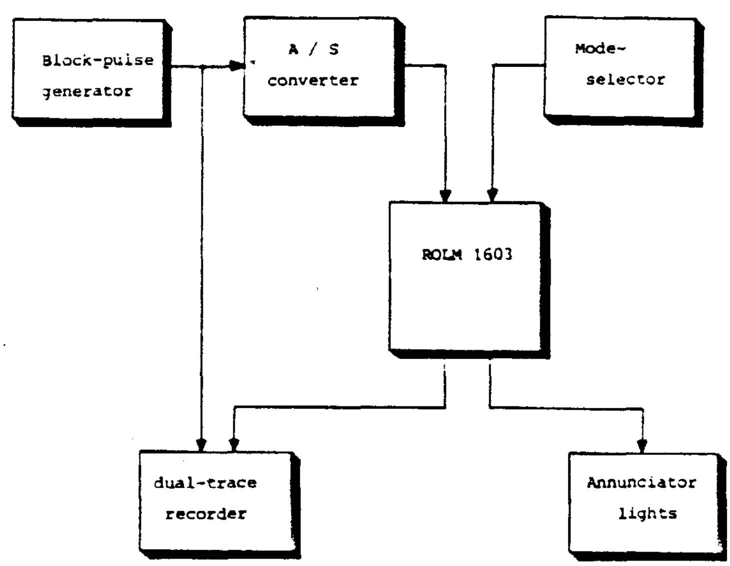

Fig.10b : Experimental set-up for determining time response characteristics (dynamic bench-tests)

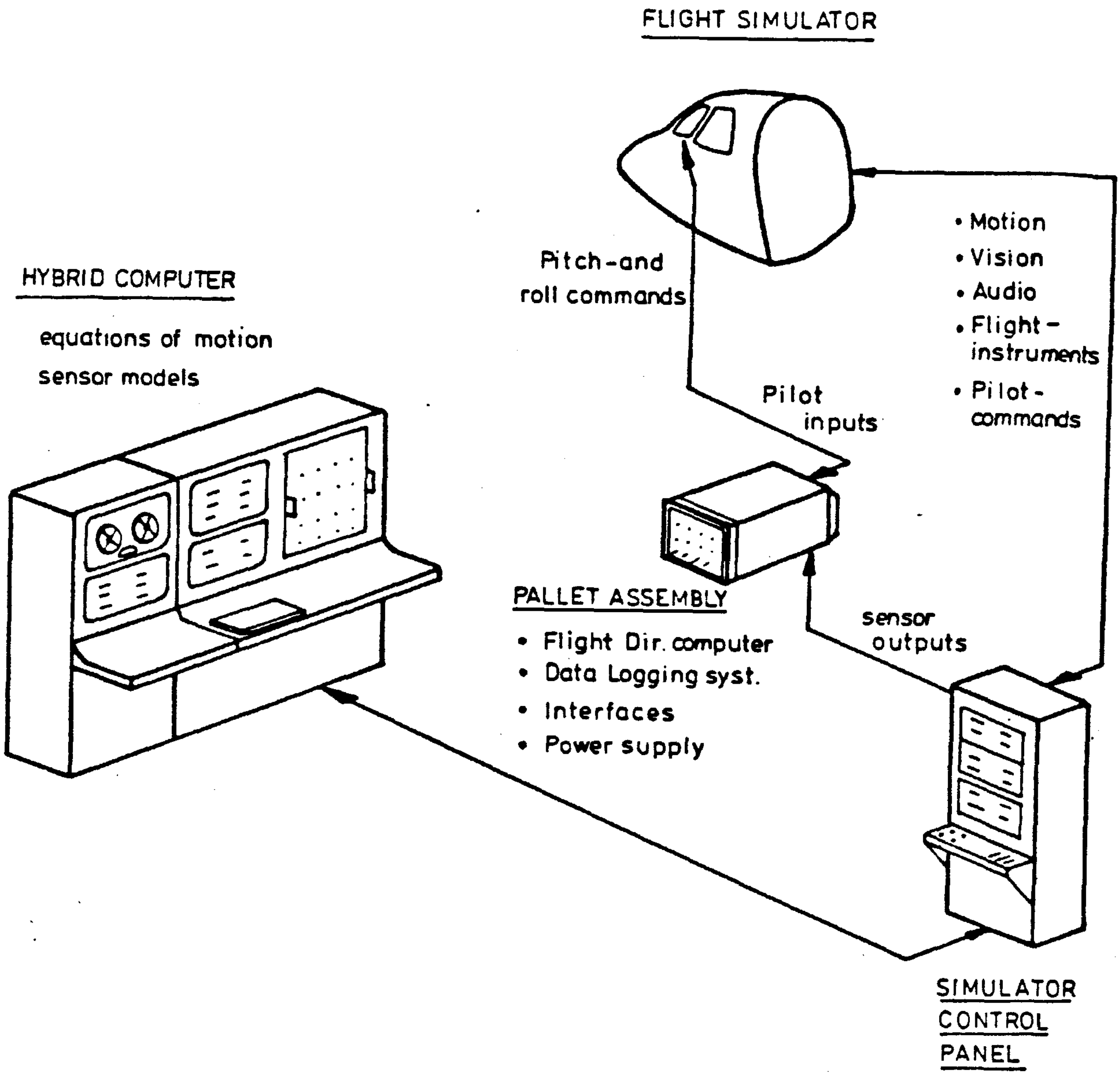

Fig.11 . Iron Bird configuration