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INVESTIGATION OF A HELICOPTER MANOEUVER DEMAND SYSTEM

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1. General Requirements

The aerodynamic properties of the helicopter allow the pilot to perform vastly different manoeuvers, like hovering, looping etc. without assistance by an automatic flight control system. Since the aircraft itself is unstable the pilot has to act as stabilizer in the case of direct control. Engaging direct forces and moments by using stick, pedal and throttle the pilot continuously changes magnitude and direction of the helicopter velocity. He compensates for continually variing disturbances caused by gusts, loadchanges etc. Pilot's sight and/or displays are the main reference for his control inputs.

Since under poor visibility in bad weather direct sight cannot entirely be substituted by displays, aircraft-stability has to be enhanced by additional technical means. The resulting loss of manoeuverability however has to be counteracted by introduction of a manoeuver demand system. For example, in order to fly over an obstacle the speed has continually to be changed, as shown in Fig.1. In the case of a velocity demand system the pilot no longer induces forces and moments directly - as shown by the bottom graph - but he simply commands translatory velocities. With other types of manoeuver demand systems (acceleration demand, angular velocity demand) the pilot retains part of the direct control functions.

The manoeuver demand system continually calculates the forces and moments *necessary to achieve* the demanded state of flight using the entire control range.

The type of signal processing required by the system is demonstrated by the following example of simplified pitch motion:

$$\Theta \cdot \dot{\omega} = -a\omega + b \cdot \eta + \zeta(\text{altitude, velocity,..})$$

disturbance

control momentum

damping momentum

The difference of the commanded rate w and the measured rate ω changes the control momentum. In order to compensate for unknown disturbances, the difference is integrated up to the point where the commanded rate has adjusted itself.

Applying the control law

$$\eta = -f_{11}\omega + f_2 f_3(w) + f_{12}\int_0^t [f_3(w) - \omega]\, dt$$

it becomes evident from the differential equation of the controlled motion:

$$\Theta \dot{\omega} = -[a + b f_{11}]\omega + b f_2 f_3(w) + b f_{12}\int_0^t [f_3(w) - \omega]\, dt + \zeta$$

that the proportional terms and the function $f_3(w)$ affect transient dynamics and system sensitivity to pilot's commands (Fig.2).

Since there is no proportionality between the control inputs and the control surface motion optimization of the pilots controls with respect to the type of manoeuver demand system is possible.

Manoeuver demand requires a redundant fly-by-wire-system in order to achieve the reliability of a purely mechanical control system. The problem of redundancy and of fault tolerance computation in a fly-by-wire-system is essentially solved.

So far price and volume of a fly-by-wire-system have prevented its application to helicopter control. In the past years, however, a low cost modular structured digital signal processing system has been developed, such that the cost problem has been shifted to the sensors. One solution to this problem is the integration of the manoeuver demand system into a totally integrated guidance and control system.

2. Experimental System

The fly-by-wire manoeuver-demand-system in its operational form is expected to permit exact control of the helicopter under extreme mission conditions. The system configuration delivering this maximum capability is called "the nominal manoeuver demand system". The system is allowed to gradually degrade down to a minimum level of performance which is called "the minimal system", with the minimum level of system performance being defined by flight safety requirements. Maximum reliability must be designed into this "minimal system".

An integrated helicopter guidance and control system for bad weather conditions (HSF) with characteristics as described above is presently being developed under a contract with the German M.D (BMVg) by Dornier, in cooperation with DFVLR, ESG and MBB. With this experimental system functional tests are being performed to obtain data on

- o fly-by-wire system characteristics
- o integrated guidance and control system capabilities
- o handling characteristics in flight under adverse weather conditions

The program is divided into three phases:

1 Development and flight test of the "minimal system"

2 System expansion to the "nominal" configuration, integration with the navigation system, and flight test of the total system

3 Incorporation of an electro-optical sensor to demonstrate system capability under low visibility conditions.

Figure 3 shows the block diagram of system configuration at the end of phase 2 of the program. The "MSR Electronics" provides all computational functions of the "minimal system", which includes the manoeuver demand control functions and inflight test routines. Inputs are the command signals w from a side stick controller and the foot pedals and the sensors (angular rates ω_x, ω_y, ω_z; attitude φ, ϑ, linear accelerations b_x, b_y, b_z). Outputs are the control signals to the servo actuators.
The inflight test routines continuously monitor the functioning of the "minimal system". In case of failure

the fly-by-wire system is Cut off and control is automatically turned over to the safety pilot.

The digital computer provides the following functions:

- o Computation of navigation equations
- o Control signal computation of the "nominal system"
- o Processing of display information
- o Processing of flight recorder and telemetry data
- o Inflight testing of sensors and BRP Electronics
- o Computer selfcheck

The "BRP Electronics" controls data input and output between the computer and "MSR Electronics", "Control and Display Panel" and telemetry system and flight data recorder.

System parameters and operational modes of the manoeuver demand system can be varied and selected by means of the Control and Display Panel. Navigational type inputs are made through the Navigation Control Panel. Major pilot's displays are: a CRT type vertical situation display, a BDH indicator and a moving map display.

The MSR and BRP Electronics use the MUDAS Modular Data Acquisition and Processing System.

The control equations were derived in cooperation with DFVLR. Equation structure and parameters were selected to obtain a system dynamic response independent of flight state variables as far as possible. Together with the linearized dynamic model of the helicopter BO 105 the Riccati-equation was applied minimizing crosscoupling between pilot's commands by means of a square performance index.

The design procedure led to numerical difficulties with acceleration demand, since in the dynamic helicopter model acceleration is not a state variable itself but a derivative of it. The consequence of this so called singular control problem and its solution is being described by the example of the simplified vertical helicopter motion:

$$\dot{v}_z = -a v_z + b \eta$$

If an integrating controller of the form

$$\eta = -f_1 \dot{v}_z + f_3 w + f_{12} \int [w - \dot{v}_z] \, dt$$

is used for acceleration demand, the sign of the highest derivative in the closed loop equation can be influenced by the factor f_1. This leads to several solutions when using automatic parameter determination. To avoid these difficulties proportional acceleration feed back was not used in numerical design and the integral part was obtained by proportional feed back of an estimated velocity $\hat{v}_z$

$$\eta = f_{12} \int w \, dt - f_{12} \hat{v}_z$$

If the estimated velocity $\hat{v}_z$ is obtained by integrating the measured acceleration

$$\hat{v}_z = \int \dot{v}_z \, dt$$

a pole of the controlled vertical velocity will lie at the origin as can be seen by the corresponding system of differential equations

$$\dot{v}_z = -a v_z + b \left[f_{12} \int w \, dt - f_{12} \hat{v}_z \right]$$
$$\dot{\hat{v}}_z = \dot{v}_z$$

In accordance with this example DFVLR used a controller configuration for defining the parameters as shown in fig. 4.

In the real helicopter model these difficulties do not arise. Since the control variables have their own degree of freedom.

$$\dot{\eta} = -\lambda [\eta - \eta_{soll}]$$

and another form of the observer equation can be used, a singular control problem does not exist and a stable acceleration demand system is obtained.

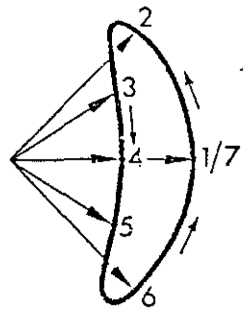
Fig. 5 shows the final control system structure providing the following combinations of control inputs:

- o Direct pitch, roll, yaw, collective control
- o Pitch, roll, yaw rate demand, direct collective control
- o Pitch, roll attitude demand, yaw rate demand, direct collective control
- o Pitch, roll, attitude demand, yaw rate demand, vertical acceleration demand
- o Vertical and horizontal acceleration demand, yaw rate demand

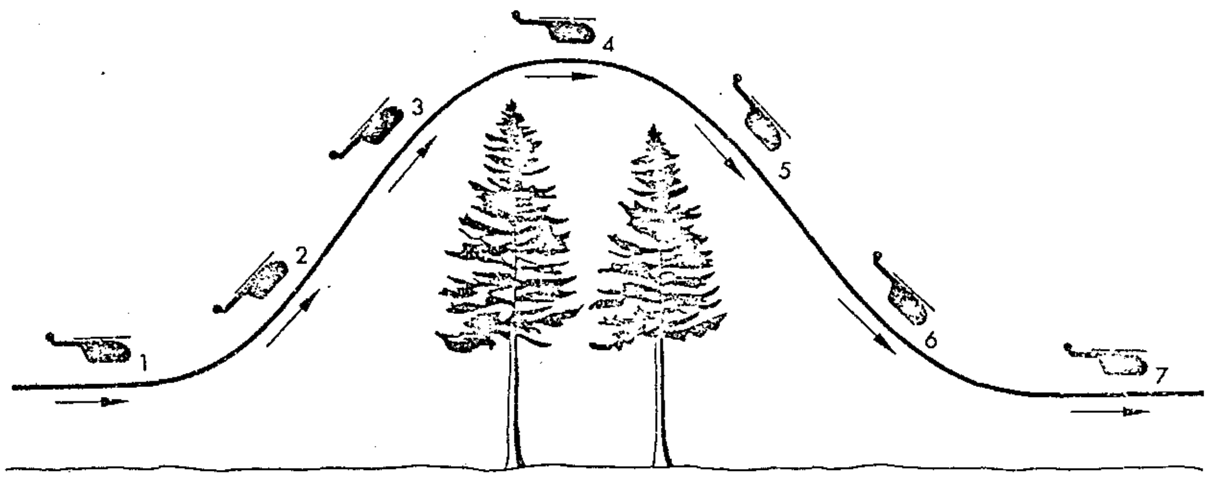
In program phase 2 the manoeuver demand system is extended to a horizontal and vertical velocity demand systems enabling hands-off-flight. Parameter values were first selected using the mathematical models. They were checked later with the aid of the Bo 105 Simulator. The required fine tuning of parameters was performed during actual flight . The test pilot himself could do this following the instructions of the engineer.

The conventional pilots control stick can be replaced in the case of fly-by-wire system. To avoid a reduction in manoeuvrability, the pilot needs four independent command inputs, and these are realized by the pedal and the side arm controller. The side arm controller developed by the DFVLR permits two rotational and one translatory control input. The controller force-displacement characteristics are generated by springs and dampers. The translatory displacement can be locked by the pilot, Fig. 6. The controller characteristics are modified by appropriate signal processing.

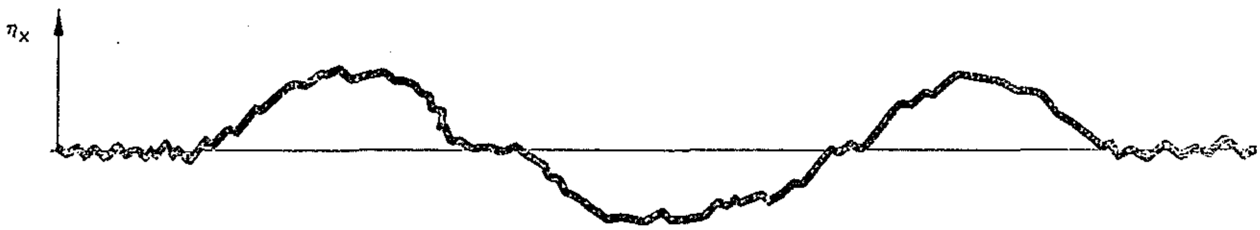
Using the side arm controller the test-pilots have flown typical manoeuvers with different manoeuver demand configurations. As the pilots received little training they experienced difficulties in handling the sidearm controller with three degrees of freedom. However, with the translatory displacement being relocated to the conventional collective stick, the controller was fully accepted by the pilots. Of the many configurations tested pilots preferred a rate demand system, since the dynamics of this systems resemble the dynamics of the standard helicopter. It should be mentioned that towards the end of the first set of tests an engineer who had never piloted a helicopter could fly manoeuvers using the acceleration demand system.



Changing of the Velocity Vector

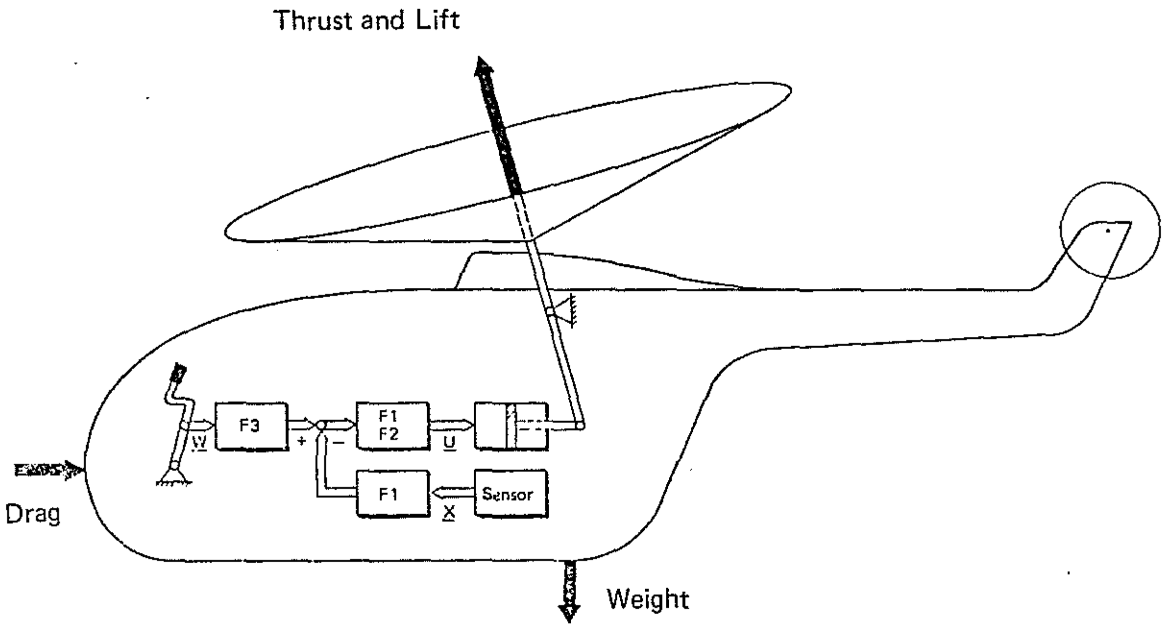


Flight Profile in Terrain Following Flight



Pilots Command Input

Fig. 1 The Terrain Following Flight



Functional Tasks of the Feedback Control System

F1 – Stability
F2 – Guidance and Control Law
F3 – Stick Sensitivity and Coordination

Fig. 2 Principle of Manoeuvre Demand System

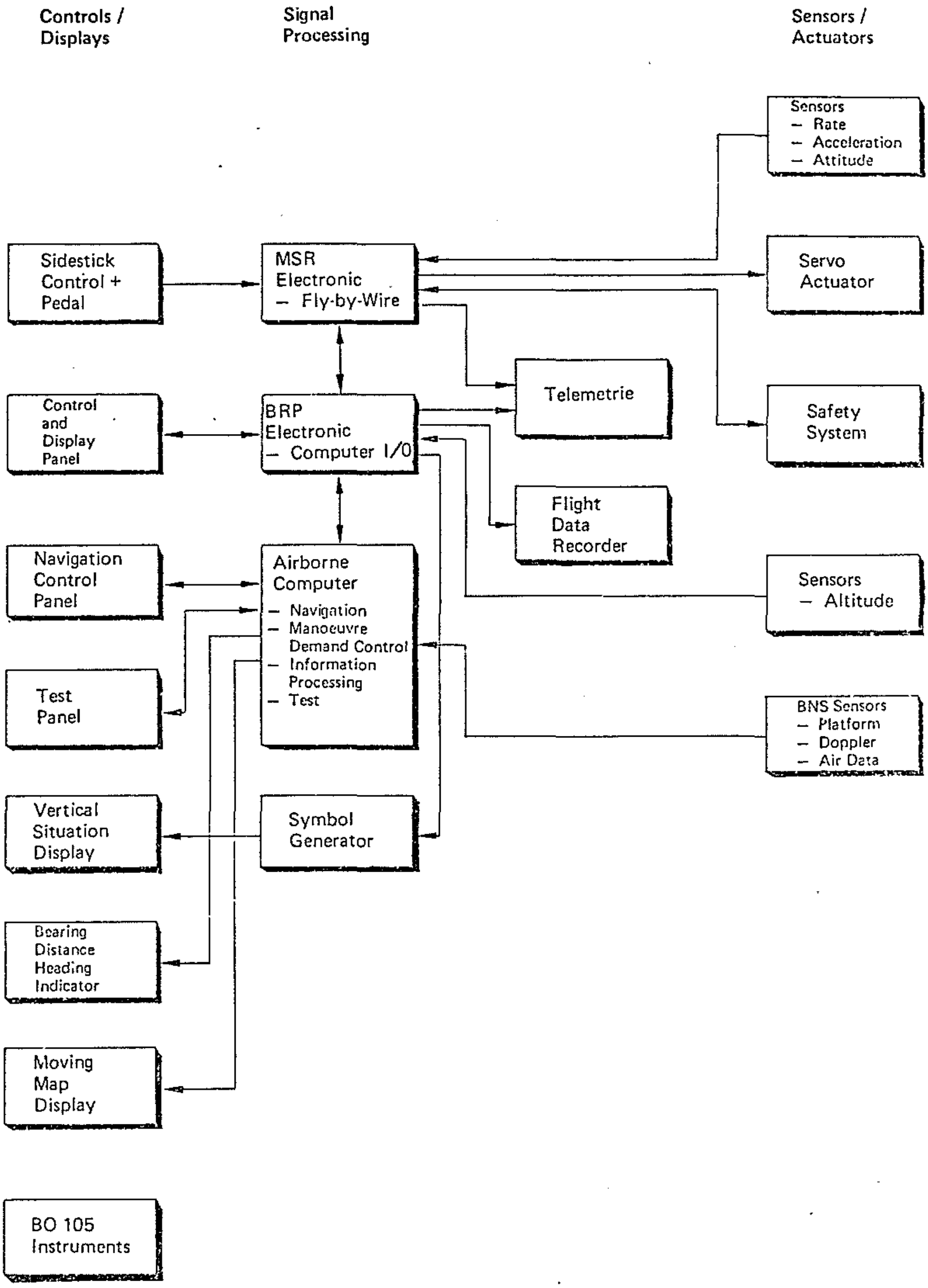


Fig. 3 Block Diagramm of the Experimental System

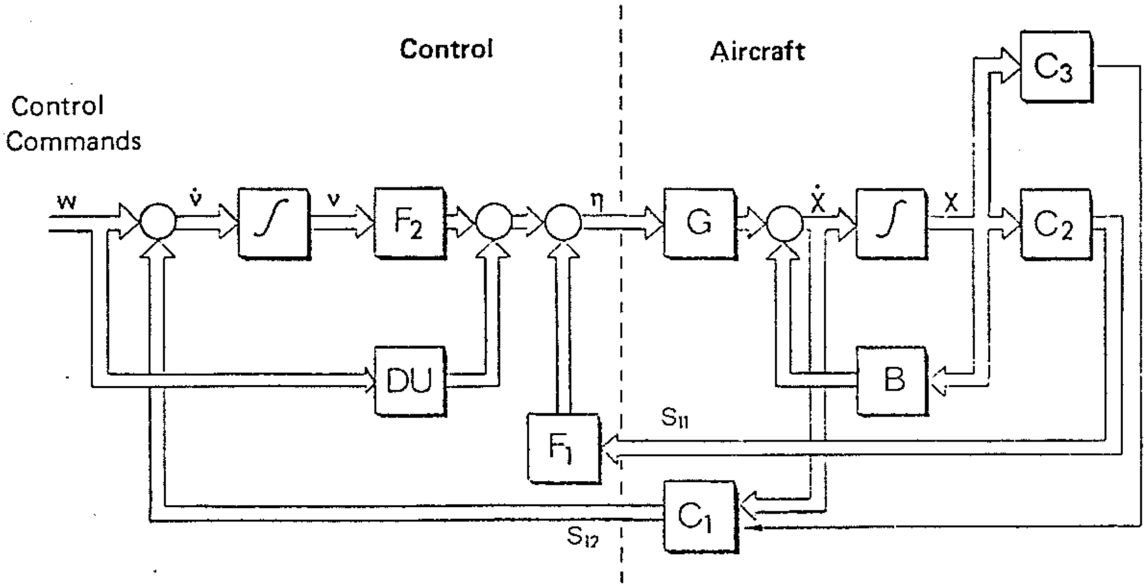


Fig. 4 Structure for Parameter Estimation of the Acceleration Demand System

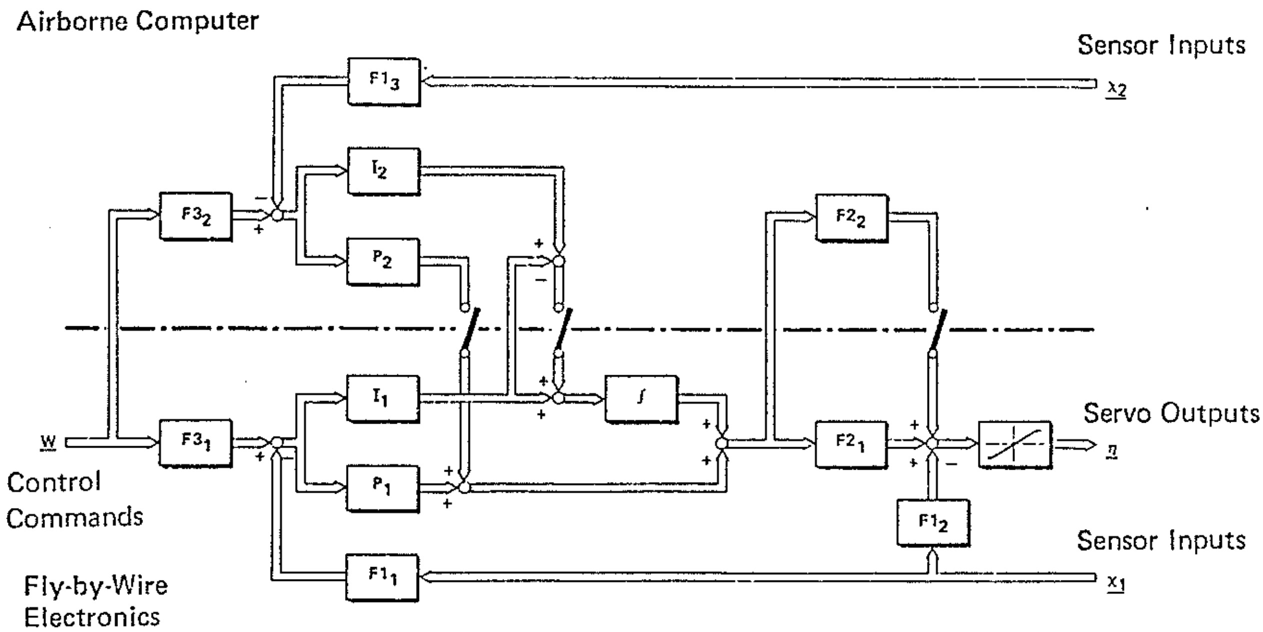


Fig. 5 Structure of Manoeuvre Demand System

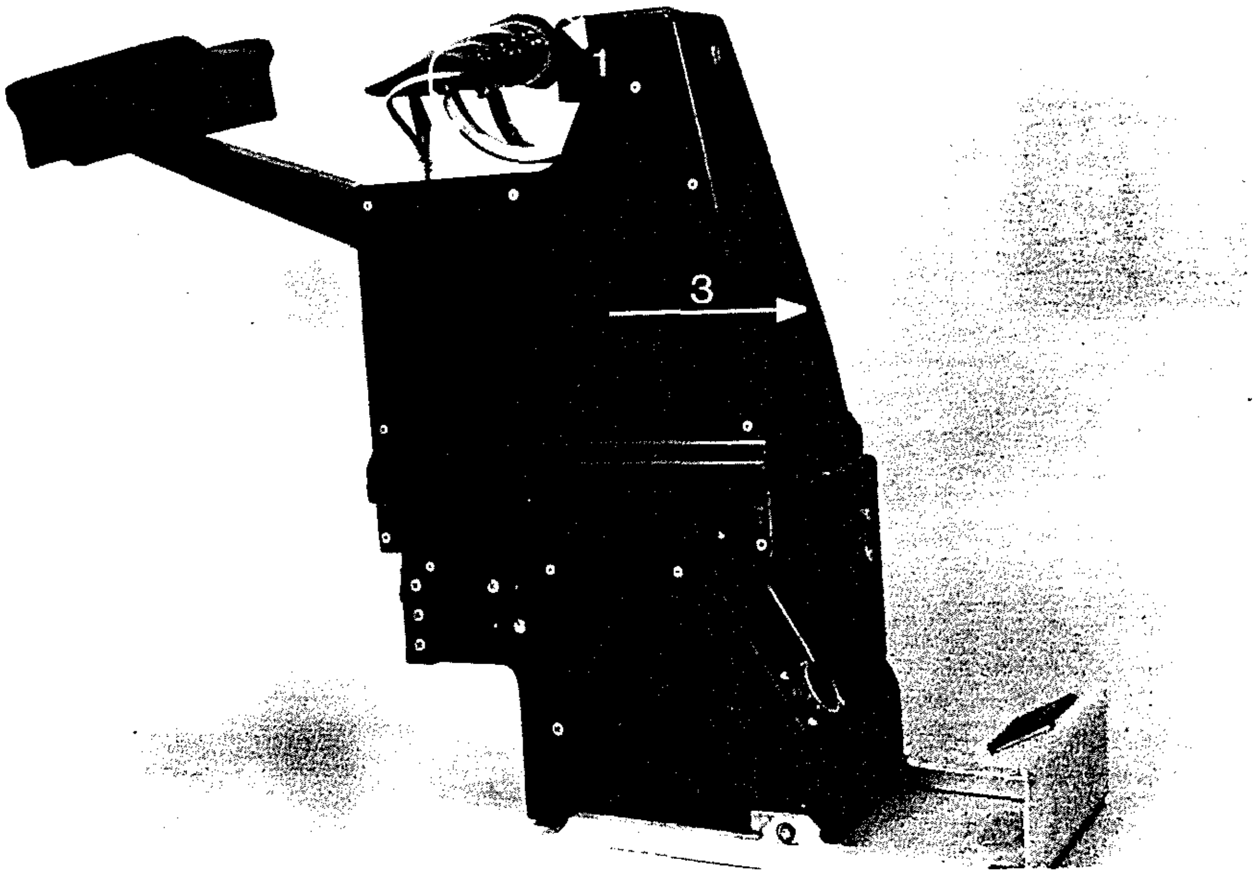


Fig. 6 Sidestick