Paper No. 30

BO 105 IN-FLIGHT SIMULATOR FOR FLIGHT CONTROL AND GUIDANCE SYSTEMS

S. Attlfellner and M. Rade
Messerschmitt-Bölkow-Blohm GmbH
Ottobrunn-Germany

Abstract

Modern tendencies of helicopter development in the last years have led to the request for special flight control and guidance systems which allow to operate at night or in poor visibility with improved handling qualities and reduced pilot's workload.

For flight tests of advanced flight control and guidance systems MBB has developed an in-flight simulator which is fitted with a digital computer as well as a nonredundant fly-by-wire control system for the simulation pilot.

The paper reports about purpose and design of the in-flight simulator. The development of special systems for safety and universal adaptability is described. Finally there is a review of present and future programs as well as a report of several experiences and results of flight tests.

1. Introduction

The development of advanced aircarft or of equipment components as well as training of pilots for new or conventional tasks ask for appropriate simulation techniques to reduce risk and cost. That applies especially to the development of helicopters and V/STOL aircraft.

A ground simulation with pilot in the loop requires a very good adaption of the cockpit area and the information of the pilot. The more realisitic a ground simulation is the higher would be the costs for the simulation due to the increased requirements for visual and other sensitive aids. Therefore it can be favourable to use an in-flight simulator if there are very high requirements for the realism of a simulation.

Extensive experiences with in-flight simulators based on helicopters as well as fixed wing aircraft have been made in Canada with the NAE-V/STOL Simulator (Bell 47) [1], [2], in the USA with helicopters like the LOH or CH53 and V/STOL aircraft like the Bell X14 [3] or Bell X22 [4] and in Germany with the airplane HFB-320 [5].

Theoretical studies at MBB in the years 1969/70 [6], [7] showed that the helicopter BO105 is well qualified as a basis for an in-flight simulator. In the following years the scope of the helicopter BO 105 for an in-flight simulator for helicopter and V/STOL flight control and guidance systems was investigated by a government sponsored program [8], [9], [10], [11].

Figure 1: BO 105 S 3

The design of the safety system and the cockpit [12], the selection of the sensors and the systems for navigation, the modifications of a BO 105 started in 1973. The first take-off of the in-flight simulator took place at the end of 1974.

2. Qualification of the BO 105 for an in-flight simulator

2.1 Safety aspects

In the following section the main characteristics of the BO 105 which guarantee a safe simulation in flight will be pointed out:

o Two engines
With a medium gross weight of 2.1 to and up to 1400 m SL there is no restriction of height above ground as a function of velocity (dead man's curve), that means that take-off and landing can be made with a large variety of glide slopes and velocities.

o Two pilots
There is no complicated redundancy in the simulation control system but an additional mechanical control system which allows the second pilot (safety pilot) to override any failure of the simulation system

o Excellent controllability
The BO 105 with the hingeless rotor "System Bölkow" offers very good controllability and damping resulting in low time constants for roll and pitch maneuvers.

o Favourable autorotation characteristics
As a function of gross weight there is the possibility of level flight or climb if one engine fails. In the case of a double engine failure it is always possible to maneuver to a steady autorotation.

o Reliability
The BO 105 is a production helicopter which results in a high degree of reliability of the components.

2.2 Scope of simulation

The scope of simulation of the helicopter in-flight simulator is defined by power and flight mechanic data of the BO 105 which are documented in [8], [9], [10],[11].
The limits are changing with gross weight, altitude and air temperature. The following data are valid for 2.1 to, 1500 m SL and ISA.

Figure 2 shows the scope of foreward, rearward and sideward velocities which are a result of both flight mechanic limits and flight manual data. The vertical velocity limits (figure 3) depend on power balance in climb and on sink rate limits in full autorotation. At high glide path angles in descent there is another region (vortex ring state) which should be avoided because of a possible high vibration level and reduced controllability. The maximum rates for pitch, roll and yaw are dependent on the differences between the control limits and the control trim positions. Therefore there are large differencies in different flight conditions.

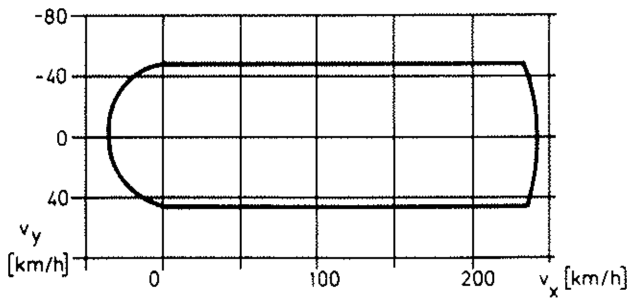

Figure 2: Horizontal velocity limits of the BO 105 in-flight simulator

3. Design of the BO 105 in-flight simulator

3.1 Cockpit and mechanical control system

Figure 4 shows the design of the cockpit and the mechanical control system of the BO 105 in-flight simulator. The seat of the simulation pilot is separated as far as possible from the seat of the safety pilot. The front part and the area in the middle of the cockpit are provided for the seat, the controls and the instrument panel of the simulation pilot and for additional electronic displays and special control panels. The seat of the safety pilot is placed behind the simulation seat on the left side of the cockpit. The safety pilot has his own instrument panels (figure 5). The safety pilot's control system is nearly the same as in a standard BO 105 with a double hydraulic system for the main rotor and without a booster in the tail rotor control circuit. There are only a few differences from the standard production system due to the different seat position.

3.2 Fly-by-wire control system

The simulation control system is designed as a nonredundant fly-by-wire system (figure 6) and is connected to the mechanical control system in such a way that the safety pilot's controls go parallel to the simulation pilot's inputs. The simulation pilot's inputs are picked up by potentiometers and led to a servo amplifier unit. The servo amplifiers drive the valves of the electrohydraulic boosters which are connected with the mechanical control system. In order to have the same control margin it is necessary to synchronize the fly-by-wire system with the mechanical system. For this reason the simulation pilot has to push a button on the control panel (figure 7) with all simulation controls free. The simulation controls are driven by the automatic follow-up-trim sy-

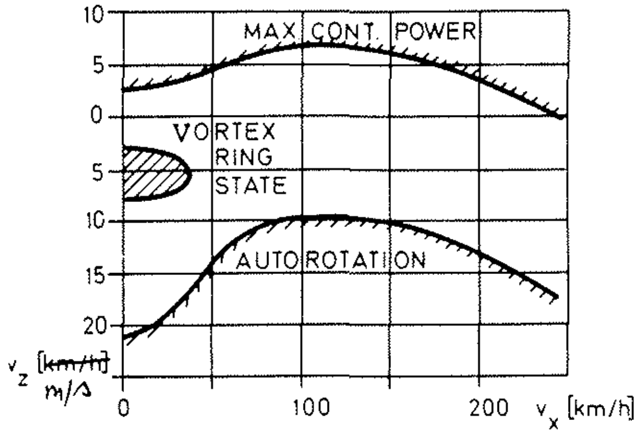

Figure 3: Vertical velocity limits of the BO 105 versus forward velocity

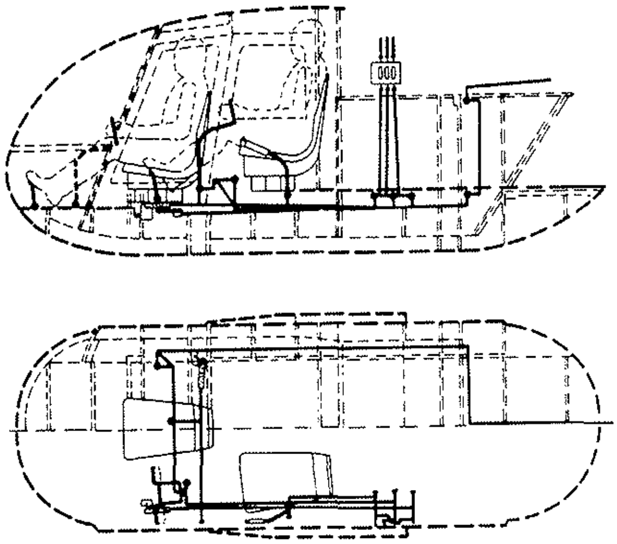

Figure 4: Design of cockpit and mechanical control system of the BO 105 in-flight simulator.

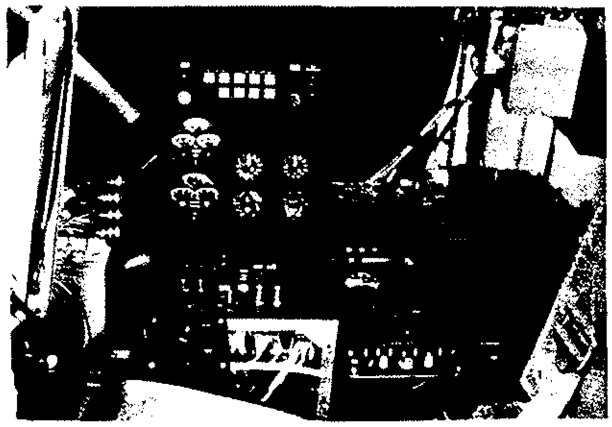

Figure 5: BO 105 in-flight simulator. Instrument panel of the safety pilot.

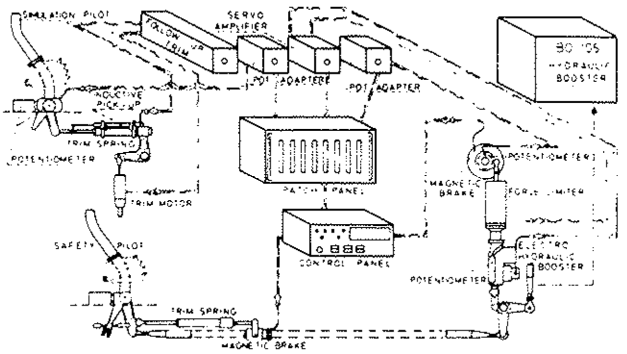

Figure 6: Fly-by-wire system of the BO 105 in-flight simulator.

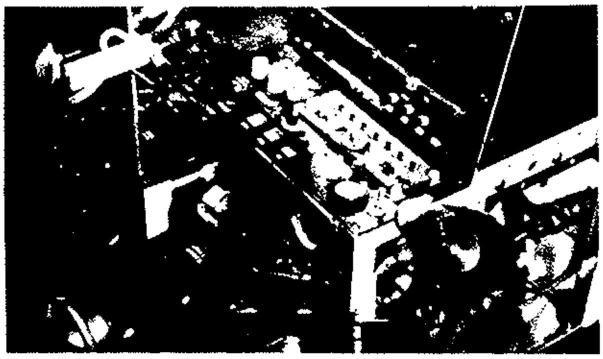

Figure 7: BO 105 in-flight simulator. Control panel of the fly-by-wire system.

stem to the same position as the safety controls. The differences between the two systems are sensored by the potentiometers near the magnetic brakes of the fly-by-wire system. If synchronisation of the selected control axes (the four axes can be selected individually) is finished, which is indicated to the simulation pilot, it is possible to connect the fly-by-wire system to the mechanical system by pushing a button on the simulation stick. The magnetic brakes of the simulation system close and the magnetic trim brakes of the mechanical system open. The simulation pilot controls the simulator and can use the follow-up-trim to have zero forces on his controls. During the simulation flight the selected and connected axes are indicated to both pilots.

3.3 Safety systems

As there is no redundancy in the fly-by-wire system with its full control authority and very high control speed (from one end of the control margin to the other about 0.9 seconds for collective, pitch and roll and about 0.2 seconds for yaw) it was necessary to provide the in-flight simulator with appropriate safety systems.

The connection of the electro hydraulic boosters to the mechanical control system is shown in figure 8. The boosters are attached with stretched springs to magnetic brakes on the fuselage. If the fly-by-wire system is off the magnetic brakes are open and the safety pilot can control the helicopter as in a standard version of the BO 105. There is also a normal magnetic trim system with trim springs in the pitch and roll axis of the mechanical system. If the fly-by-wire system is switched on by pressing a button on the stick of the simulation pilot the magnetic trim system is switched off and the magnetic brakes of the fly-by-wire system are closed. The controls of the safety pilot are now coupled with the control inputs of the fly-by-wire system. If there is any malfunction of the simulation system or if the simulation is finished, both pilots can cut off the fly-by-wire system by pressing a switch on the stick

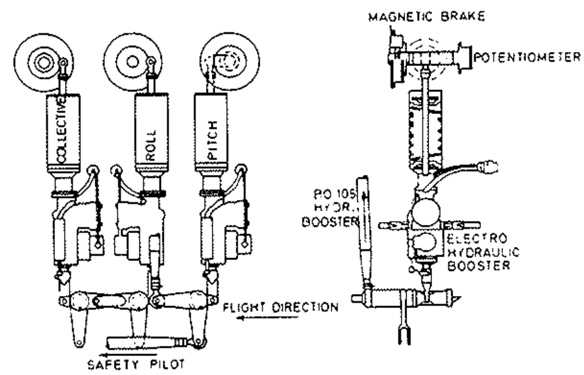

Figure 8: BO 105 in-flight simulator; connection of fly-by-wire and mechanical system.

which disengages the fly-by-wire brakes and magnetic trim system. So the stick of the safety pilot is fixed at the actual position when the emergency switch is pressed. The emergency circuit is designed to be redundant and can be checked before starting the engines. Nevertheless if the simulation brakes don't open, the safety pilot can override the system because of the above mentioned springs. In this case it is uncomfortable for the pilot because the control forces are reasonably high with extreme brakeout characteristics.

In addition to these safety systems which depend on pilot's activity there are several automatic systems which increase the safety of the simulator. The first one is a monitoring of the rotor shaft bending moment. If an adjustable bending moment is to high there is an automatic procedure which has the same results as the pressing of the emergency button. Similar to the shaft moment limitation there is a limitation of main rotor blade in-plane bending moments. The principle of these two monitoring systems is shown in figure 9. The monitor signals are periodical. To avoid influences of short voltage picks, which result from inductive loads on the aircraft network, the first comparator does not cut off the system if the adjusted limit is exceeded but starts an integrator with a constant input. A second comparator gives a signal to the emergency cut off circuit if an adjustable voltage is exceeded by output of the integrator.

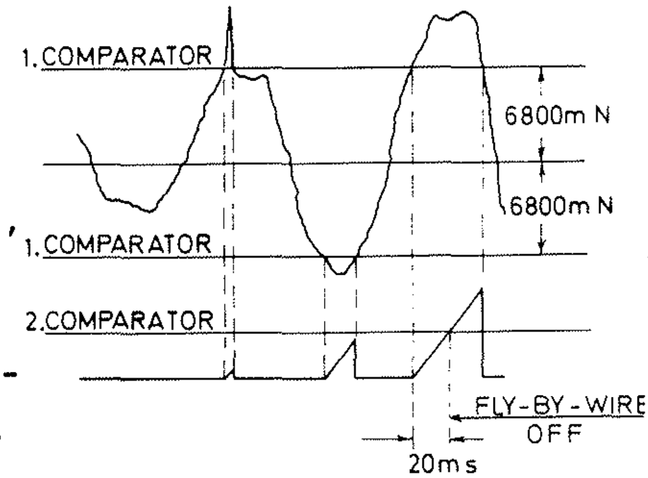

Figure 9: Monitoring of shaft moment of the BO 105 in-flight-simulator.

Expecially for the simulation of advanced flight control systems on this computer equiped in-flight simulator there is a third automatic safety system which allows to reduce the control authority. This is favourable if there is any malfunction of the computation or if there is a mistake in the design of the flight control system which leads to instability. The limits of the authority are gliding, that means quick control inputs are limited and slow inputs are unlimited (figure 10). Both the margin for the quick inputs and the gliding speed are adjustable.

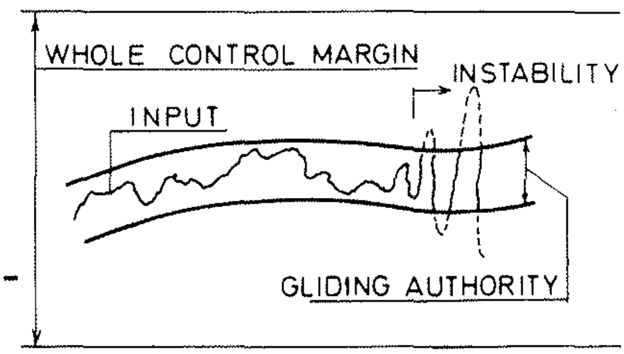

Figure 10: Authority limits of the BO 105 in-flight simulator.

3.4 Systems for universal adaptability

The BO 105 in-flight simulator is designed for universal purposes. There are different design characteristics and special systems for universal adaptability. For example there is sufficient space in the simulation area of the cockpit (figure 11) to install additional instrumentation and displays as well as different control

Figure 11: BO 105 in-flight simulator; simulation area of the cockpit.

Figure 12: PDP11 digital computer in the BO 105 in-flight simulator.

mechanisms, for example side-arm controllers. The unusual large loading space of the BO 105 offers very good possibilities for the installation of computers and other simulation systems which could be placed out of the pilots sight. A normal commercial computer installed on a pallet in the loading space is shown in figure 12. This computer with several digital to analog and analog to digital converters is part of the basic equipment of the simulator. The computer (PDP11 from Digital Equipment) is rather large and heavy but has the advantage of easy programming and handling [13]. A further and very important device for universal adaptability is the central patch panel (figure 13). All signals coming from or going to sensors, pick-ups, computers, instruments, actuators and so on are available on this patch panel. So there is the possibility of free connection of the different systems. In addition there is a large number of functions for the adaption of different signals as sign changers, amplifiers, demodulators and relais functions.

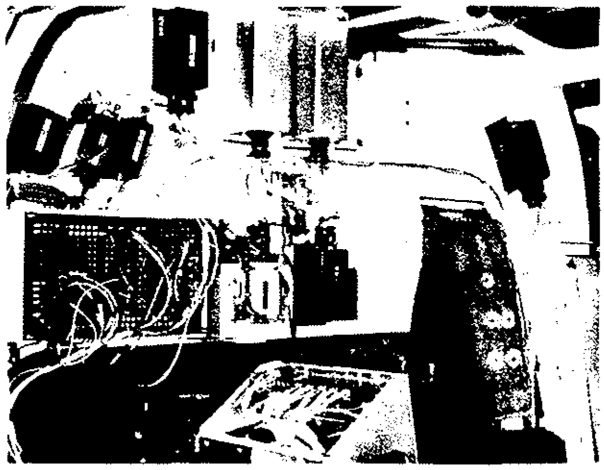

Figure 13: BO 105 in-flight simulator central patch panel.

3.5 Sensor equipment

In addition to the normal sensor equipment of the BO 105 it is necessary for every simulation program to have special sensors for the measurement of the flight conditions. It was considered to be uneconomical if the necessary sensors for all expected programms with its different demands for accuracy would be part of the basic sensor equipment. Nevertheless, there are some additional sensor systems, like a radio altimeter from Collins, a Sperry flight-director system and low-airspeed-measurement systems from Marconi Elliot (LASSIE) and Nord Micro (Vortex sensor).

4. Flight tests of fly-by-wire and safety system

As the servo loops of the electro hydraulic system were ground tested it was considered to have no problems with the fly-by-wire control system in normal operation. But there could be difficulties with synchronization and with malfunctions. The first take-off took place in the end of 1974. The safety pilot needed some time to become familiar with his unusual seat position as there were differences in sight and acceleration information compared with a normal BO 105. The first fly-by-wire tests were carried out in about 1000 m above ground in level flight in the most uncritical speed range of 60 to 80 kts. The synchronization tests showed that synchronizing of all four axes was always possible when the safety pilot controlled the helicopter with smooth inputs. As expected there were no problems in the following tests, where each of the four axes were made active while the safety pilot controlled the remaining three axes. After this all axes of the simulation system were engaged together. The simulation pilot was pleased with the exact controllability and the possibility of trimming all control axes to zero forces.

It was the main purpose of these flight tests to establish the safety of this in-flight simulator in the case of malfunction of any component of the simulation system. It was shown that run away of the actuators was no problem for the safety pilot in the first few minutes when he was extremely on the alert. But it was considered that there could be difficulties in longer simulation flights. This was the reason for the above mentioned shaft moment monitoring which increases safety expecially in run away of the collective and the pitch axis. Although there could occur very large bank angles in the case of run away of the roll axis there were no problems because the hingeless rotor offers excellent controllability in the whole range of load factors.

5. Realized and expected programs

The first simulation program started in January 1975. The purpose of this simulation was to test an advanced control system for helicopters [14] which provided automatic stabilisation as well as command inputs with totally decoupled control axes. The first flight tests with the digital computer in the loop [15] showed that the new signal line (pilot-analog to digital converter-computer-digital to analog converter-electro hydraulic booster) was working well expecially in the view of synchronization. The only problem was that it was very uncomfortable for the safety pilot and probably disadvantageous for the BO 105 hydraulic system that the digital outputs of the computer led to very hard control impulses at the short cycle time of 50 ms. The problem was solved by the installation of additional analog filters. The following simulation of the advanced control system consisted of optimizing the digital computer program and of testing the system at different flight conditions in forward flight. The hover tests and the simulation with this

Figure 14: Adapter box for remote control

system at low airspeeds and different glide path angles will take place in the next months.

A second program was realized in the meantime. It could be demonstrated that the remote control of a helicopter was very easy to achieve with a system which is normally used for remote control of small flying models. It was only necessary to design an adapter box to have proper signals for the inputs into the fly-by-wire system. The mounting of this box and the receiver antenna on the helicopter is shown in figure 14. Figure 15 shows the remote control pilot together with the remote controlled BO 105.

The next program is the development and test of an advanced flight guidance system. This program will be done in cooperation with Dornier, DFVLR, and some other companies. The purpose of this program is to test new techniques of displays and control systems (side-arm-controller) in combination with an advanced flight guidance system. The program which is very extensive will be carried out in the next two to three years.

Figure 15: Remote control of BO 105.

6. Conclusions

In the first simulation programs the BO 105 in-flight simulator with all its systems has proved its qualification in about 50 hours of flight test. The helicopter was always ready for use and had no malfunctions of any part of the whole system. The cost effectivity of this in - flight simulator was proved in the first simulation program where the optimizing of a complicated digital flight control system could be estabilished within a few hours of flight test. In addition to the above mentioned next program it is also planned to do simulations of new helicopter concepts.

7. References

1. D.F. Daw, The NAE Airborne Flight Simulator. Canadian Aeronautics and Space Journal Volu. No. 4, April 1965.

2. W.S. Hindson, The NAE Airborne V/STOL Simulator as a Design and Development Tool for V/STOL Aircraft. Canadian Aeronautics and Space Journal, Dez. 1970.

3. Artikel über das V/STOL-Forschungsflugzeug Bell X-14B, Interavia 11/71.

4. J.L. Beilmann, X-22A Variable Stability System. 1st National V/STOL Aircraft Symposium AHS, Nov. 1965.

5. B. Uhrmeister, Eignung der HFB-320 HANSA zur Simulation des Schnellfluges, Wartefluges und einer Standardkurve eines schweren Kampfflugzeuges. DLR-Bericht, 1970.

6. H. Schmitt u. P. Ehrensperger, Hubschrauber variabler Stabilität mit gelenklosem Rotor als fliegender Simulator. DFVLR Symposium über Simulation im Fluge, 6. Mai 1969.

7. K. Janik u. H. Schmitt, Hubschrauber BO 105 als Versuchsträger variabler Stabilität-Aufgabenstellung und Realisierungsmöglichkeiten. Bericht MBB-UD 52-70-Ö, 12.6.1970.

8. M. Rade u. S. Attlfellner, Vorbereitende Untersuchungen für BO 105 als Flugversuchsträger für Drehflügler- und V/STOL Flugführungssysteme. MBB Bericht UD-78-71, 30.11.1971.

9. M. Rade u. S. Attlfellner, Grundlegende Untersuchungen zu einem Hubschrauberversuchsträger für V/STOL-Flugführungssysteme. MBB-Bericht UD-74-71, 20.12.1971.

10. S. Attlfellner, Untersuchungen der Grenzen des Hubschraubers BO 105 beim Einsatz als Flugversuchsträger für die Erprobung von V/STOL-Flugführungssystemen. MBB TN-D121-10/71, 18.12.1971.

11. S. Attlfellner, Flugmechanische Grenzen eines Hubschrauberversuchsträgers für die Simulation von V/STOL-Systemen. MBB-TN-D121-9/71, 14.1.1972.

12. H. Derschmidt, Steuerung und Cockpit für BO 105 als Flugversuchsträger. MBB-TN-D125-2/71, 20.11.1971.

13. O.F. Nielsen, Digitaler Flugregler PDP11 für HSV BO 105 -Systembeschreibung Ausgabe A. MBB-TN-FE324-1/74.

14. Korte u. Alt, Hybride Mehrgrößenregelung. MBB UFE 1055 10.12.1975.

15. O.F. Nielsen, Integration des digitalen Flugreglers PDP11 in den HSV BO 105/S3 und die durchgeführten Flugversuche mit dem Proportionalprogramm 1:X. MBB-TN-FE324-4/74.