RESONANCE AND CONTROL RESPONSE TESTS USING A CONTROL STIMULATION DEVICE

Hubert Müller
Flight Test Engineer

Deutsche Aerospace - MBB
Helicopter Division, Munich, Germany

ABSTRACT

Since June of this year two prototypes of MBB's new light-twin helicopter, the BO 108, are flying and providing successful test results. Both aircrafts are equipped with a stimulation device for main rotor control inputs. Many kinds of collective or cyclic inputs can be chosen in a computer menu. It is possible to select the longitudinal and lateral signals separately or in combination. Each input is of an accuracy which no pilot can offer. Thus, a better response analysis can be done if the helicopter's motion is also measured.

The different components of the stimulation system and their functions and performance are described. Examples of ground and flight testing are presented for various subjects like ground and air resonance, flight mechanical control response and engine characteristics. For comparison, diagrams of former helicopter testing with manual control inputs are shown and discussed.

Currently, the BO 108 is investigating the new 'STIMULI'-functions SAS-mode and ATT-hold for both pitch and roll axis. These additional functions are intended to eliminate cross coupling effects and to reduce time required and pilot's workload for flight test.

Last but not least a further function, the on-board data monitoring in text or graphical mode is also in operation.

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INTRODUCTION

At MBB a new light-twin helicopter, the BO 108 model, is in the development flight test phase. In 1988, with the first prototype (PT1), the investigations begun on advanced main rotor and tail rotor technology, compact main transmission and hydraulic unit, composite airframe structure, etc.
Since June of this year, the BO 108-PT2 is providing successful test results with TURBOMECA engines (TM 319-1B) installed with full authority digital electronic control (FADEC).
Both prototype helicopters (Figure 1) are also equipped with novel measurements and test augmentation systems.

The BO 108 aircraft itself was already introduced at various European and American Meetings of helicopter experts. This paper concentrates on one item of the special equipment, the Control Stimulation Device, which is installed for better performance of ground and flight tests.
First, a general description of the 'STIMULI'-system is given. The second part demonstrates the various applications of computer controlled main rotor inputs, and the resulting helicopter response behaviour.
For comparison, helicopter testing with manual control inputs is also shown.

Fig. 1
BO 108 Helicopters PT1 and PT2

STIMULI - SYSTEM

The 'STIMULI'-apparatus, a programmable signal generator for main rotor control inputs, was developed and built in our flight test instrumentation department.
Presently, that device is adapted to the BO 108's hydraulic system with integrated servo actuators for electrical signal inputs.
Thus, the preselected STIMULI-command is superimposed on the pilot's control inputs.

If necessary, the STIMULI-system can also be configured to operate with electro-mechanical actuators as used in the BO 105 and BK117 helicopters for SAS-functions.

Description of Components

As shown in Figure 2, the STIMULI-system consists of four hardware parts:

1. Computer Unit

The IBM-AT compatible computer is installed in the helicopter's cargo compartment and is supplied with 28 V DC. Inside the computer the following cards are installed on a passive bus board:

PROCESSOR CARD -
10 MHz cycle frequency, 1 MByte Ram

RAM CARD -
operating system and utility programs

EPROM DISK -
for extended data storage, 1 MByte

DISPLAY CONTROLLER -
IBM-Hercules mode for LCD-display

SERVO INTERFACE -
connects the actuators to the servo loop and releases the safety shut-off valves

The dimensions of the computer box are 360x170x250 mm (length, width, height) with a total mass of 6.6 kg.

2. Control Panel / Emerg. Cut-Off

The STIMULI control unit is integrated in the middle console of the helicopter. It consists of an IBM-AT compatible keyboard and a 28V master switch.

KEYBOARD FUNCTIONS

- 'numbers' 0, 1...9 (number of storage) for preselecting control signals
- 'arrows' for cursor drive (up, down, left and right)
- 'star' for jumping to the first position of program menu (home function)
- 'rhomb' starts the preselected function (carriage return function)

MASTER SWITCH

- ON/OFF function for computer and safety shut-off valves
- emergency shut-off function with locking latch for OFF position

DIMENSION

- 146x120x100 mm (length, width, height)

WEIGHT

- 0,75 kg

EMERGENCY CUT-OFF SWITCH

- located on the pilot's stick

3. LCD-Display

The screen is mounted on the left side of the instrumentation panel, i.e. in the field of view of the flight test engineer, who is operating the STIMULI-system. For optimal illustration in text and graphical mode the display has a resolution of 640 dots horizontal and 400 dots vertical.
A contrast adjustment as well as a background lighting is available to give a perceptible cockpit display by daylight and in darkness.

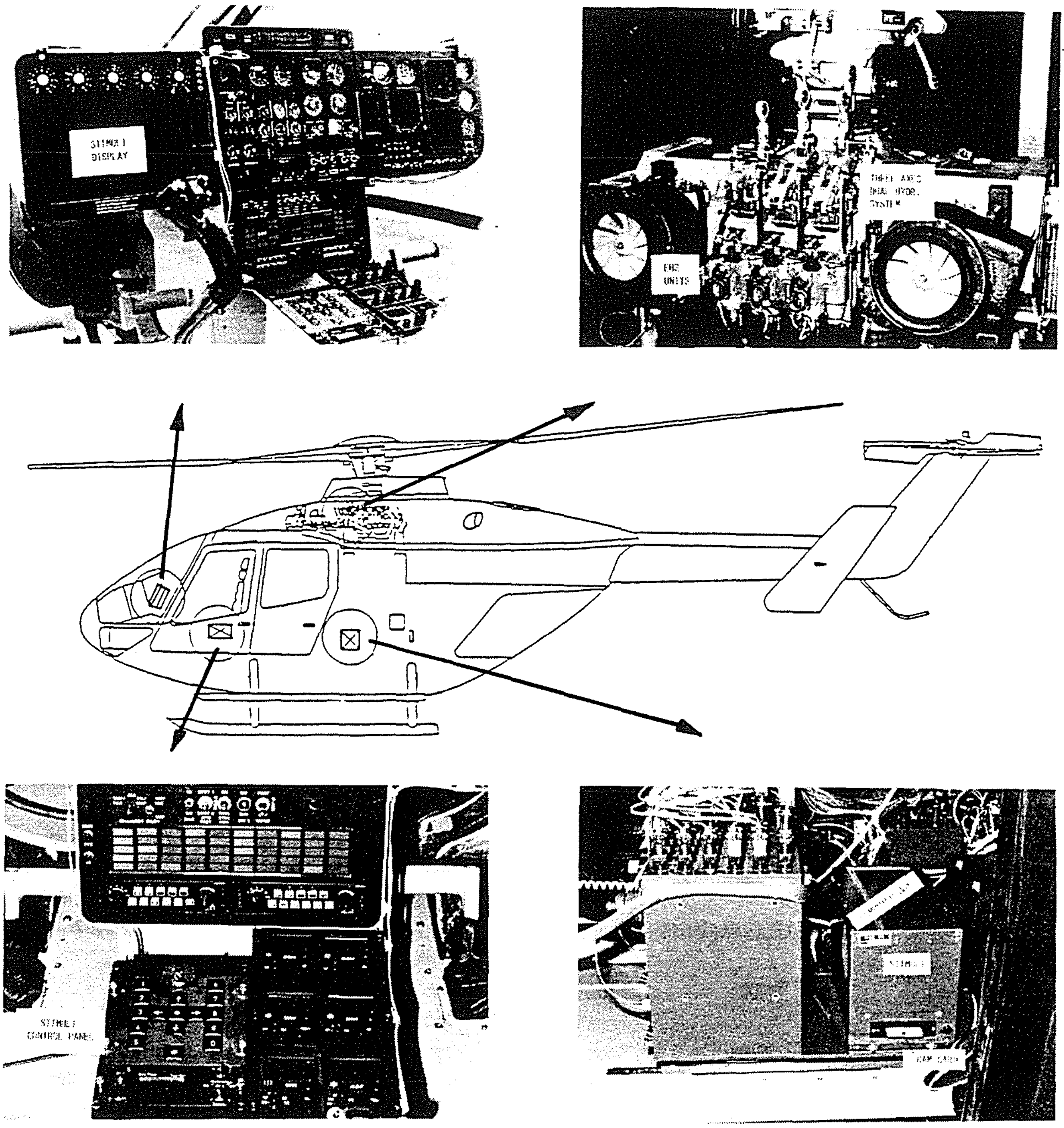

Fig. 2
Components of STIMULI-system for BO 108

Power to the display is controlled from the STIMULI control panel master switch. The dimensions of the screen are 200x285 x60 mm (width,height,thickness) and the weight is 1.7 kg.

4. Electro-Hydraulic Servo Unit

Three EHS are connected direct to the hydraulic governor units of the longitudinal, lateral and collective pitch control axes. For each axis the servo control output is mechanically coupled to the pilot's control input as shown in Figure 3.

Thus, the automatic and manual inputs are superimposed and the resulting input is fed to the main hydraulic actuator.

Figure 4 shows a cross-section of the servo unit. The actuator of each control axis has a stroke of 8 mm and every 10 ms the input command for the active axis is given . The LVDT measures the position of the regulator piston. If the safety shut-off valves close, the servo actuators will self center in middle position.

The electro-hydraulic servo unit for each control axis weighs 1.3 kg.

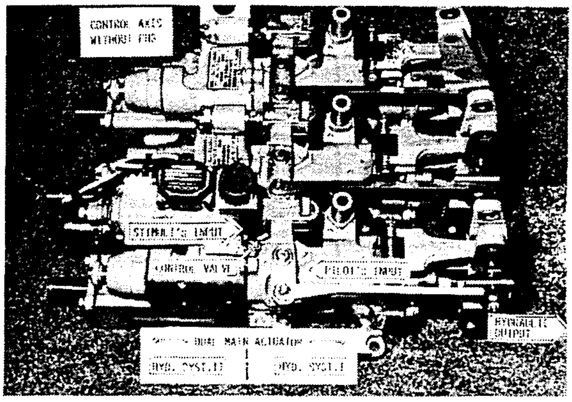

Fig. 3
Hydraulic control servo

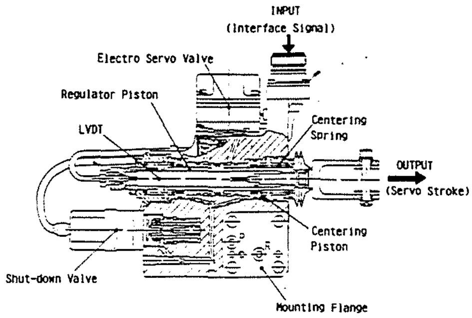

Fig. 4
STIMULI servo unit

Control Authority

All control authorities of the STIMULI-servo units were determined with reference to the existing BO 108 control travels. For the longitudinal, lateral and collective pitch control axes, the current authorities are as follows:

Control Axis	STIMULI-Authority
cyclic pitch	13%
cyclic roll	23%
collective pitch	21%

Operation and Program Menu

After switching on the STIMULI-system, a self test is run, the operating system program will be loaded and then the utility program can be started with code '111'.

The first display contains the program menu (see Figure 5). Each function can be chosen by pushing the relevant arrow key on the control panel.

Normally, the first task is to prepare a control input. It starts with the input select function and in the next step the type of signal has to be chosen (Figure 6).

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STIMULI PROGRAM

CONTROL INPUT      EDIT/CHANGE

PRESELECTED INPUTS
1  2  3  4  5  6  7  8  9  0

START OF INPUT

FREQUENCY CHANGE   + 0.05   - 0.05
MAGNITUDE CHANGE   + 5.0    - 5.0

INPUT FILE LOAD

INPUT FILE SAVE

BACK TO OPERATING SYSTEM PROGRAM
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Fig. 5
Utility program functions

```
INPUT SELECT

SINGLE AXIS:  PITCH
              ROLL
              COLLECTIVE

STICK WHIRL:  CYCLE RIGHT
              CYCLE LEFT
              TILT RIGHT
              TILT LEFT
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TYPE

SINE

RECTANGLE

PULSE

SWEEP
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Fig. 6
Choice of input signal

After these general informations, the input parameters must be defined. For those details see Figure 7.

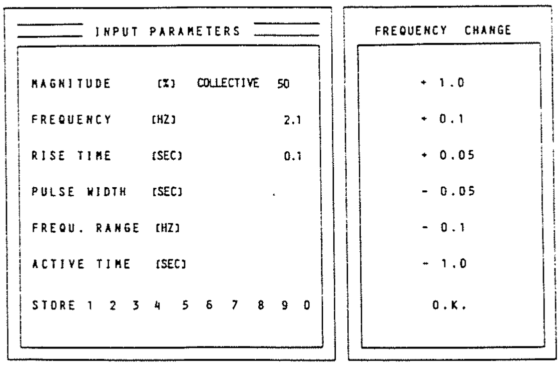

Fig. 7
Parameter definition

If the control input is correctly described, it can be saved directly to one of ten available memories. When pushing the relevant number again the input is ready for start.

At the end of the edit function the cursor line automatically jumps to the 'START OF INPUT' position in the program menu. For the final check, the input parameters are listed below the menu display (Figure 8).

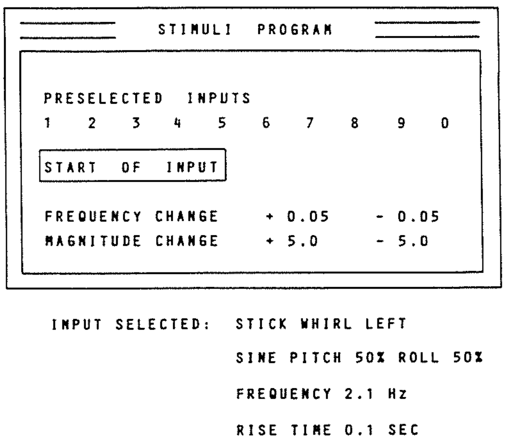

Fig. 8
Display of preselected STIMULI input

When pushing the thromb key (carriage return) the actuator selected moves and the input signal is also plotted down on the STIMULI-screen.

Additionally, for temporary changes of preselected inputs a quick frequency or magnitude correction is possible. – The remaining functions of the program menu are self explanatory and also simple to use.

Control Signal Variety

As mentioned before, the STIMULI-program offers automatic control inputs in three axes separately and a combination for cyclic longitudinal and lateral. For the latter, a so-called 'Stick-Whirl', the relation between pitch and roll amplitude is adjustable and the phase has to be selected synchronous to the h/c's rotating direction or against it.

For each axis the following types of a control input are possible:

1. Sine or Rectangle (Figure 9)

Frequency
- 0.1 Hz to 10 Hz in steps of 0.05 Hz

Amplitude
- 0% to ± 50% in steps of 1%

Rise Time
- 0.1 sec to 180 sec in steps of 0.1 sec

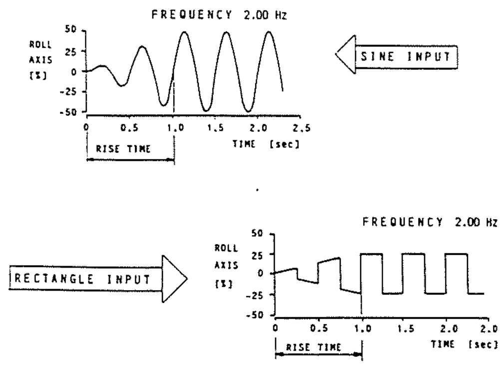

Fig. 9
Sine and rectangle inputs

2. Pulses (Figure 10)

Duration of pulse
- 0.1 sec to 180 sec

Magnitude of pulse
- 0% to 50% or 0% to -50%

Rise/decay time
- 0.1 sec to 180 sec

If an input of more than + 50% or -50% is necessary, then the actuator must first be brought in the opposite direction. After that the input starts, when pushing the 'arrow up' key. This procedure also offers a doublet pulse input.

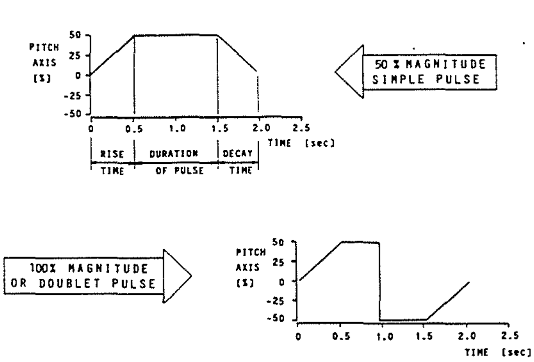

Fig.10
Example of pulses

3. Sweep (Figure 11)

Frequency range
- 0.1 Hz to 10 Hz in steps of 0.1 Hz

Amplitude
- 0% to ± 50% in steps of 1%

Time for run
- 10 sec to 300 sec in steps of 1 sec

During the run the current frequency is displayed.

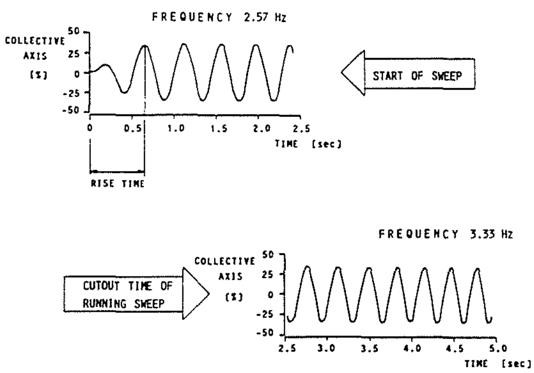

Fig.11
Example of frequency sweep

EXAMPLES OF RESPONSE TESTING

A new test method with computer controlled main rotor inputs is described. The various control signals are compared with pilot inputs and the response data of the helicopter are also shown.

Ground Resonance Tests

Before testing new rotor systems in flight, extensive ground runs are necessary. One of these is the resonance stability test of the helicopter with inplane main rotor excitation.

Normally, the blade oscillation has to be induced by the pilot's cyclic stick motion of a certain amplitude and frequency. For that, 'Stick-Whirl' inputs with small frequency steps of 0.1 Hz (sometimes 0.05 Hz) have to be performed to find out the exact natural frequency of the system. In addition, an amplitude variation also is necessary for optimum damping evaluation.

During testing with manual Stick-Whirl excitation at MBB, an audio signal of the desired excitation frequency is transmitted to the pilot for reference. The synchronization to the frequency and the pitch/roll amplitude ratio required are difficult to attain and are not always correct (Figure 12). Therefore, the main rotor blade chordwise bending moment and the helicopter's pitch rate are not of constant amplitude during excitation. Moreover, when the input should stop, it is difficult for the pilot to go back immediately to the initial cyclic control position. Thus, the first part of the decay process is not usable for damping evaluation.

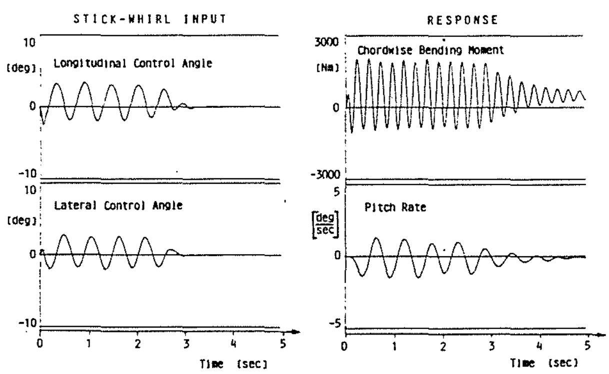

Fig.12
Manual Stick-Whirl excitation

If the STIMULI-system is used, exact control inputs can easily be achieved. The distinct frequency and amplitude combinations required are available quickly and the excitation is constant (Figure 13).

After pushing any key, the inputs for pitch and roll axis stop when the sinusoidal cyclic excitations are going through zero. Thereby optimum data analysis is possible in consequence of accurate inputs.

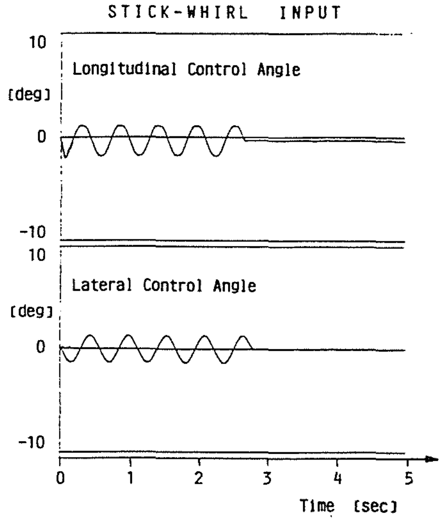

Fig.13
Automatic Stick -Whirl excitation

Air Resonance Tests

As described for ground runs. The same is applicable for air resonance tests in hover, level flight, climb and descent.
Only the response is another one, i.e. the helicopter's roll rate shows the resonance condition to the rotor inplane excitation (Figure 14).

In flight the STIMULI-system supplies both best inputs to the main rotor and minimum workload to the pilot. While automatic control amplitudes are active, the pilot can stabilize the initial flight condition and, in addition, he has a better possibility to react correctly if required by unforeseen events.

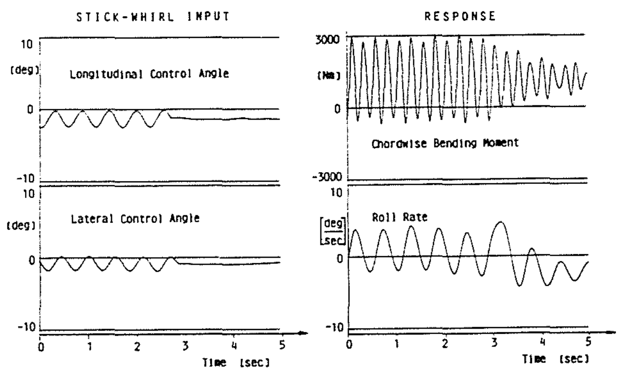

Fig.14
Air resonance test with STIMULI

Vertical Oscillation Investigations

Another use of the STIMULI equipment is the investigation and exact determination of vibration/oscillation modes in flight. For example, the helicopter's response to a short collective pitch pulse input was measured (Figure 15). The aircraft's reaction, a vertical oscillation with a time periode of approximately 0.2 seconds, was of small amplitude.

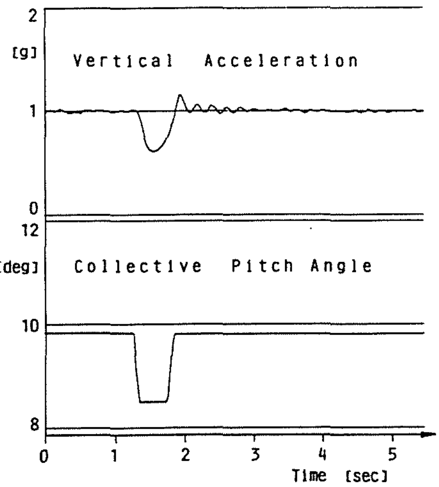

Fig.15
Aircraft response to a pulse input

In the next step, collective pitch sine inputs were performed starting at 4.5 Hz and up to 5.5 Hz to determine the vertical oscillation exactly. At 4.9 Hz the natural frequency of this mode was found as shown in Figure 16.

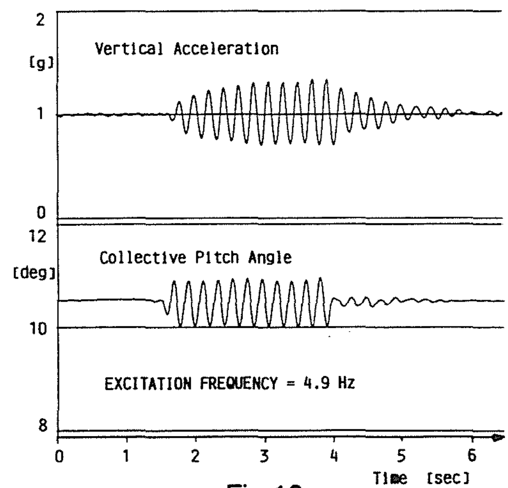

Fig.16
Aircraft response to a sine input

The aircraft's response was a damped oscillation with seven cycles after the end of the sine-excitation, induced by the collective pitch control system. After some modifications to the friction mechanism of the collective lever the small vertical oscillation after sudden collective pitch inputs was eliminated.

Collective pitch excitations at frequencies as done by STIMULI would be very difficult to perform manually, and much less accurate. Thus, test performance and data analysis is faster and more cost-effective.

Flight Mechanical Control Response Tests

In hover as well as in forward flight the helicopter's response to cyclic stick and collective pitch inputs has to be analysed. During hover flight exact step inputs on the stick are not easy, even for experienced pilots. In the input's time history the change-over from the slope to the constant deflection should be of an exact repeatable shape. But for manual inputs this transition is often arched and the pilot's trend of stick motion is back to the initial control position (see Figure 17).

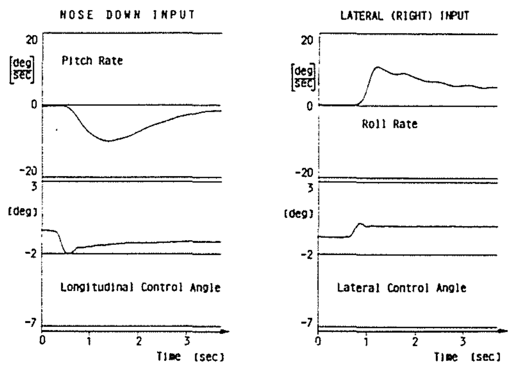

Fig.17
Pilot's cyclic step-inputs
in hover flight

For better pilot inputs the flight test engineer often gives assistance on board by supporting a moveable stop to the control column.

The results of longitudinal and lateral control step inputs using a manually moveable stop show an improvement (Figure 18). But the change-over from slope to constant deflection in both axes, pitch and roll, are not satisfactory.

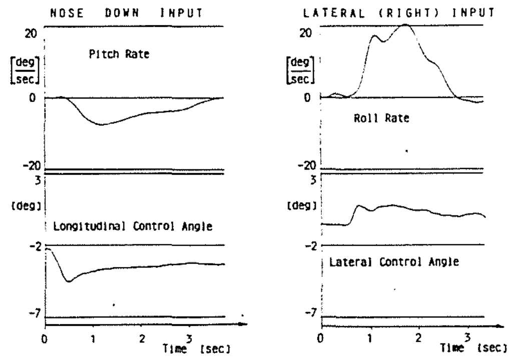

Fig.18
Pilot's inputs with
manual control stop

However, the best main rotor control inputs for all axes with high accuracy are supplied from the hydraulic servo actuators. The STIMULI-system enables the crew to prepare automatic control commands as desired (Figure 9) and the inputs of chosen direction and magnitude can be activated by the flight test engineer when the pilot has stabilized the initial condition.

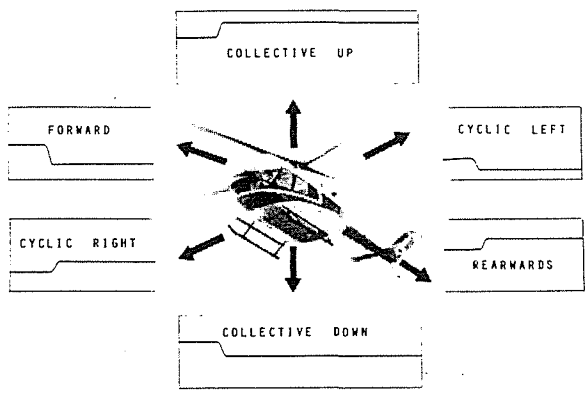

Fig.19
Automatic control inputs by STIMULI

Engine Response Testing

A further area of STIMULI-application is engine characteristics and torsional stability testing. For example, the response of both engine torques were measured following an upward collective pitch step input (Figure 20).
The fuel control adjustment of the engines is responsible for the resulting change in power. The rotor speed behaviour of the PT1 helicopter is also plotted down simultaneously.

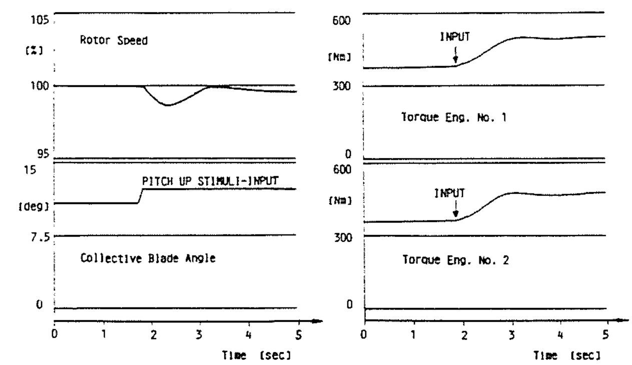

Fig.20
Engine response to a collective pitch step-input

Finally, I want to present another interesting use of the STIMULI-system. It is important to find out the resonant frequency of the engines' drive system. For that investigation a frequency sweep starting at 0.1 Hz up to 0.9 Hz was selected in the collective pitch axis to excite the drive system of the BO 108 PT 1. An example of the STIMULI input signal as well as the engine torques and the main rotor speed are shown in Figure 21 for an early configuration of the fuel control system.

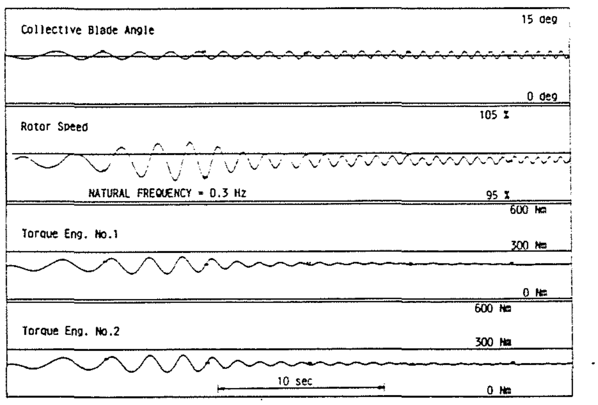

Fig.21
Frequency sweep in collective pitch axis

A maximum amplitude in the relevant response signals was determined at 0.3 Hz. After some modifications to the fuel control system significantly improved behaviour was found, with no trend to increasing oscillations.

Similar frequency sweeps in collective pitch axis were performed to test the FADEC of the PT2 engines.

CONCLUSION

This presentation has concentrated on the main functions of the STIMULI-system presently used for ground and flight testing of the BO 108 helicopters. The pilot's workload is considerably reduced, because he only has to stabilize the initial flight condition while the automatic main rotor control input occurs. Improved accuracy of test results and very substantial savings in flight test and data analysis time and cost are achieved.

A second function of the STIMULI-computer is also in operation. Independent of telemetry ground station, on-board data monitoring is possible. From the helicopter's instrumentation pack a list of maximum fifteen channels can be indicated on the screen in text mode. For each measurement signal a digital on-line information is given about maxima and minima, respectively. In graphical mode the time histories of two channels can be watched simultaneously.

Finally, initial tests were performed with the new STIMULI-functions SAS-mode and ATT-hold for both pitch and roll axis. That operation eliminates cross coupling effects, and also reduces time required and pilot's workload for flight test.