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Evaluation Of A Pilot's Line-Of-Sight Using Ultrasonic Measurements

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A b s t r a c t

In a short review the general task of evaluating a pilot's line-of-sight by determining the three angles of movement azimuth, elevation and roll is described.

In a visually coupled system these angles are used to direct a camera,for example, according to the movement of a pilot's helmet.

The AEG solution described is based on the measurement of the transmission time of ultrasonic signals between transmitters mounted on the cockpit structure and receivers on the pilot's helmet.

A short description of the achieved technical solution including hardware is given - discussing also the technical problems, e.g.

- immunity from echoes and interference
- immunity from cockpit noise
- air temperature and actual speed of sound

as well as technical data for the angular and translational coverages.

Finally a short presentation of the mathematical systemanalysis used to evaluate the required angles azimuth, elevation and roll depending on time measurement mentioned above is given.

EVALUATION OF A PILOT'S LINE-OF-SIGHT

USING ULTRASONIC MEASUREMENTS

This report about the development of hardware and software to determine a pilot's line-of-sight using ultrasonic measurements covers the following items :

1. Description of the complete system (HMD/LOSL/ACP)
2. Objective of the line-of-sight locator (LOSL)
3. Concept
4. Realisation of a hardware prototype line-of-sight locator
5. Experience/technical problems in development and testing
6. Mathematical solution
7. State of work

Figures :

1. Description of the complete system (HMD/LOSL/ACP)

The helmet-mounted display (HMD) with line-of-sight locator (LOSL) system, developed by AEG, has been designed to support aircraft pilots or navigators in their fulfilment of all mission requirements, by day and night, even under adverse weather conditions.
The whole system consists of three subsystems:

(1) helmet mounted display (HMD)

(2) line-of-sight locator (LOSL)

(3) 3-axis controlled platform (ACP)

The helmet-mounted display (HMD) displays flight, navigation and fire-control information directly in front of the pilot's eye (symbology and/or TV pictures).

The line-of-sight locator (LOSL) coupled with the helmet-mounted sight allows

- designation of a target or
- automatic movement of a camera/sensor

corresponding to the movement of the pilot's helmet by simply looking at the object or scene.
The line-of-sight locator detects the present helmet position relative to the aircraft frame and provides the three angles

azimuth, elevation and roll data

of the line-of-sight .

The 3-axis controlled platform (ACP) is used as a base for mounting eg.

a camera, armaments or range finder.

The platform is slaved to the azimuth, elevation and roll data from the line-of-sight evaluation.

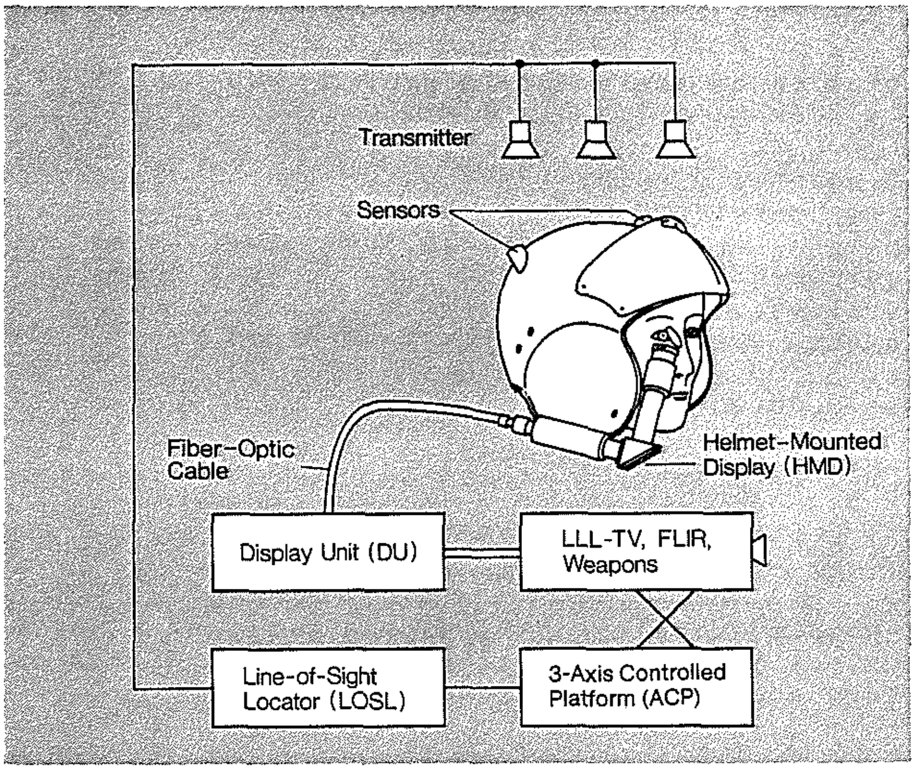


Fig.1 Complete System HMD/LOSL/ACP

2. Objective

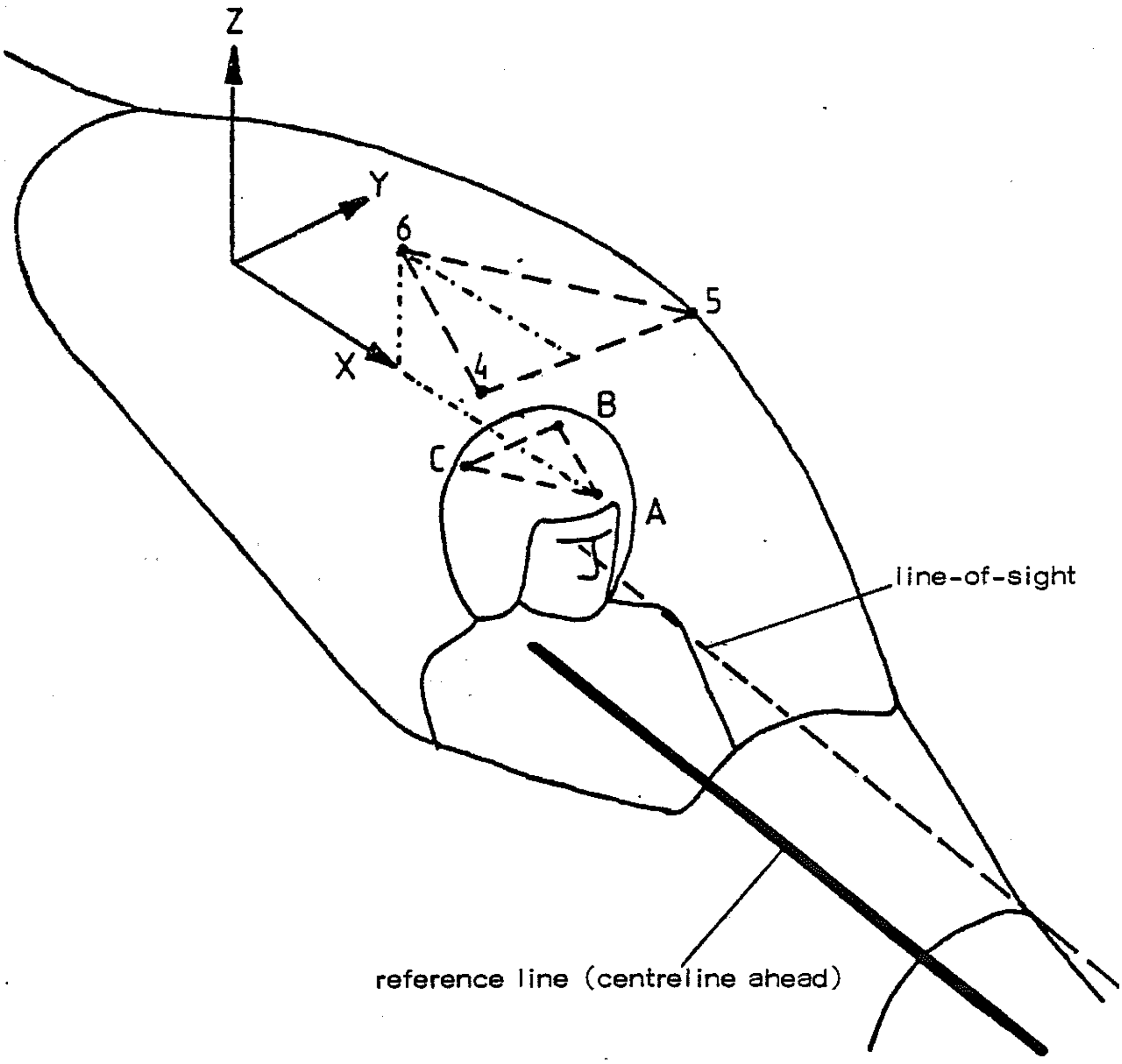
The objective (see Fig. 2) is to determine the angles of deviation in the azimuth, elevation and roll axes of a pilot's or observer's line-of-sight from a fixed reference. This objective is to be fulfilled with an **accuracy of 0.1°** and at a speed sufficient to determine every change of head position (i.e. approx. 20 measurements/sec).
Using the angles of deviation obtained, a sensor e.g. camera, can be slaved to follow the pilot's or observer's line-of-sight. Prime examples for application are helicopters and aircraft.

The fixed reference is understood to be the aircraft centreline ahead.

The line-of-sight is a line referenced to the pilot's helmet. This is assumed to be identical to the direction of viewing of the pilot.

To achieve this assumption a system to maintain constant eye position is rigidly mounted on the helmet. Using this method no relative movement between head and helmet is allowed.
The specification of rotational and lateral movement of the helmet is defined in the following table .

Fig.2: Objective of line-of-sight locator



Helmet movement detection

Rotational	Azimuth	+- 90°
	Elevation	+- 70°
	Roll	+- 35°
Lateral range	X-Axis	+- 15 cm
	Y-Axis	+- 25 cm
	Z-Axis	+- 10 cm
Accuracy	Helmet position detection	+- 0.1°
Slew rate	120° /sec	

3. Concept

AEG's solution to the afore-mentioned objective, is based upon calculations derived from the time of transmission of ultrasonic signals.

These signals are transmitted from ultrasonic transmitters (at least 6) mounted rigidly in the cockpit to strike obliquely the rear side of the helmet. The signals travel between 10 and 50 cm before being received by the ultrasonic receivers (min 3/ max 6) mounted on the helmet.

The angles of deviation in each of the three axes can be calculated using the transmission time of digital pulses between each transmitter and each receiver.

Movements of the helmet can cause certain transmission paths to be no longer measurable (due to low signal levels, i.e. receivers are in the helmet's "shadow"). These are intentionally excluded by the signal processing hardware.

With the number of transmitters and receivers quoted above, more paths than necessary are available for the mathematical calculations. Additional paths permit the possible errors to be minimized.

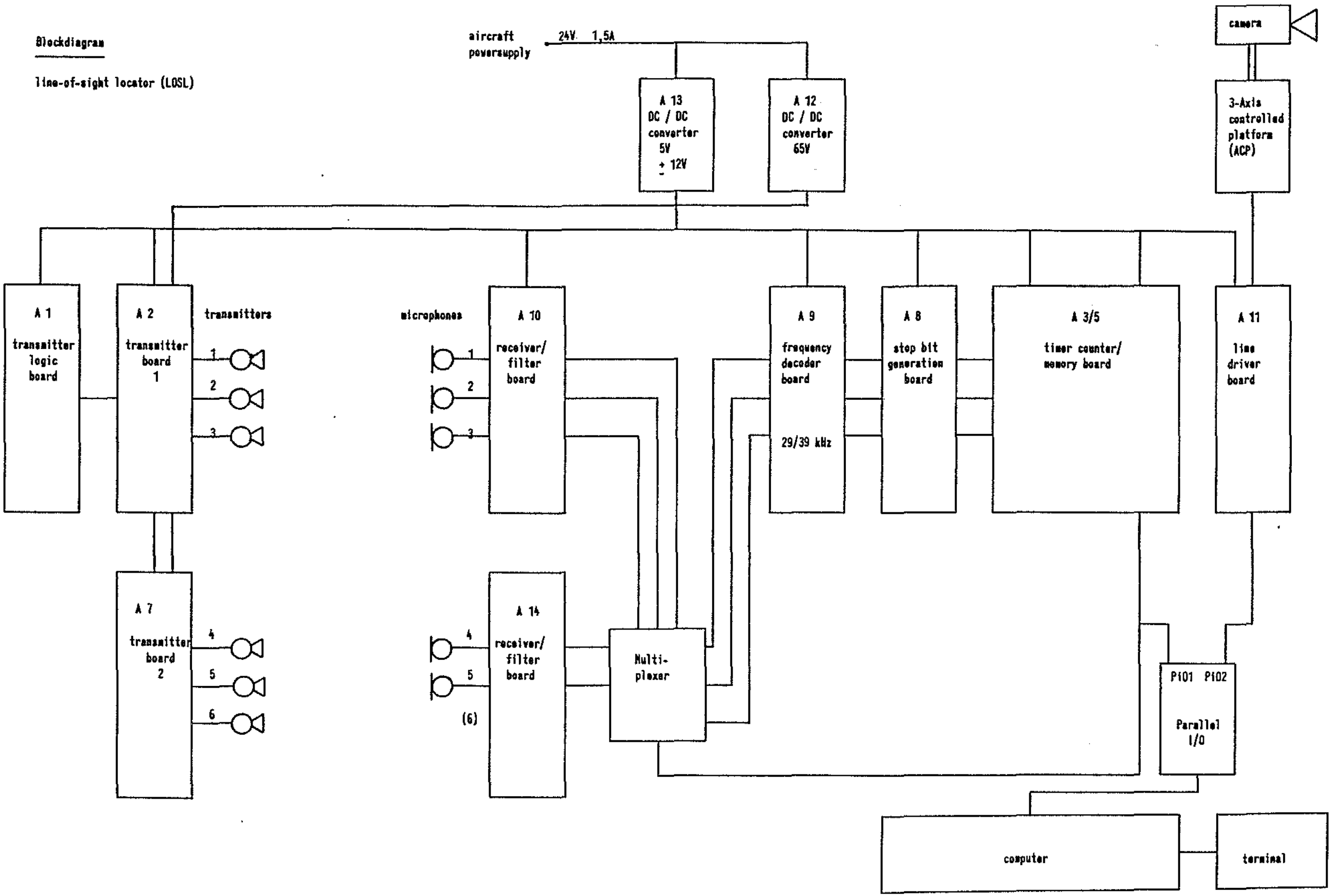
4. Realisation of a hardware prototype line-of-sight locator

A prototype line-of-sight locator has been developed and manufactured (boards in Europe-format).
The layout of the system is depicted in the following block diagram.(see Fig. 3)
The power for the line-of-sight locator is derived from the aircraft onboard supplies and is converted internally to the necessary DC- voltages.
The sequential formation of the digital pulse sequence at ultrasonic frequencies for each of the transmitters is performed by the transmitter boards.
To minimize the influence of the purely mechanical transient response between quiescent and transmitting states of the ultrasonic transmitters, the system is operating during non-active phase with a base frequency of ca. 29 kHz. The active phase is performed at a frequency of ca. 39 kHz. Frequency change is to occur at zero signal amplitude.
The ultrasonic signals available at the receivers are decoded. The transmission times of the ultrasonic signals between each transmitter (6) and receiver (min 3) can be measured based on the time elapsed.
The transmission times are used to calculate the angles of deviation in each of the three axes (azimuth, elevation, roll) from the fixed reference line. The angle information is passed via the necessary driver board to a follow-up 3- axis platform on which a sensor, for example, is mounted.

During development an 8-bit Z80-CP/M-computer was used. The testing phase was started with a very simple model.
Present development and testing is being carried out on a lifesize helicopter mock-up using a 16-bit computer (68000).

Blockdiagram

line-of-sight locator (LOSL)



5. Experience gained and technical problems arising during testing

During the testing phase the following technical problems or factors were confronted:

(1) different mechanical transient response of the transmitters and receivers.

(2) significant dependence of the speed of sound upon the environmental conditions (e.g. temperature, humidity)

(3) neighbouring ultrasonic sources in the same frequency band creating interference.

(4) significant air currents passing between the transmitters and receivers.

(5) sonic reflections and interference

(6) transmitters in the "sound shadow" of the helmet .

Each individual point can be clarified as follows:

(1) The influence of the mechanical transient response of the transmitters between quiescent and transmitting states is reduced by driving them during non-transmission with a base frequency of ca. 29 kHz. This permits an easier transferance to the transmission frequency of ca. 39 kHz.

(2) The significant influence of variations in the speed of sound caused by environmental temperature or humidity fluctuations can be eliminated by constantly determining the speed of sound. This is achieved by measuring the transmission time of an additional path, which is superfluous for line-of-sight determination and then computing the speed of sound.

(3) The false transmission times created by additional undesired ultrasonic sources can be eliminated by the following means:
a) The start- and stop-signals must be digitally coded so that any interfering ultrasonic sources cannot influence the start- and stop-signals used to determine the transmission time over any path.
b) The base and transmission frequencies (29 kHz and 39 kHz) can be increased in order that any natural noise sources which exist in a helicopter or aircraft, are no longer noticeable in the ultrasonic range used.

During flight tests in a Bell UH-1D helicopter it was found that no sources of interference to the transmitted signals or measurements in the ultrasonic range were present.

(4) Significant air currents (fans, open windows or doors) can be avoided by suitable integration of the transmitters in the cockpit area. The area behind the pilot's head is particularly suitable. Areas, where equipment or cockpit ventilation occur, must be avoided.

(5) The influence of reflections arising from the cockpit structure can be avoided by making the transmission pulse time short. The time of transmission for a particular path can be measured before any reflected signal is received.
In addition the pulse repetition frequency (PRF) must be adjusted so that the amplitude of a transmitted pulse is reduced after several reflections before the next pulse to be measured is transmitted.
Additionally suitable location of the transmitters within the cockpit reduces reflections and interference problems.
It may be useful to cover the helmet with a soundabsorbent surface.

(6) In spite of the fact that due to movement of the helmet some receivers will be in the "sound shadow" of the helmet, it is assured by making a suitable number of measured transmission times available (min.9) that all angles of helmet position within the required ranges are detected. This is achieved by integration of a higher number of transmitters (min 6) and receivers (min 4) into the system .
In this way additionally measured paths can be used to improve the calculation of angle data and minimize errors. Those paths with a very low signal level - caused by the receivers being in the "sound shadow" - are intentionally masked out by the hardware.

6. Mathematical solution

The mathematical objective is to calculate the following 7 unknown values using all available transmission times measured. The number of transmission times available is higher than absolutely necessary for a plain calculation (min 9):

- **3 rotational angle data:** azimuth, elevation, roll — sent to the platform

- **3 lateral data :** x,y,z
  (those values are purely used within the calculation)

- **actual speed of sound**

In addition all fixed coordinates of all transmitters are available within a system of coordinates related to the centreline of the aircraft.
Two methods of calculation and the corresponding computer programs have been developed.
Additional safeguards and controls have been incorporated into the program, e.g. limits of angle data for the 3- axis-platform.

6.1 **Continous Solution** (without Iterations)

Starting from all transmission times measured, at first the actual coordinates of all receivers on the helmet are determined by minimizing squared errors. In a second step the lateral values are eliminated. Afterwards all rotational angle data (3) are calculated via a continuous, nonlinear system of equations without iterations.
The actual speed of sound is calculated based upon one transmission time of a path and known/calculated coordinates of transmitters and receivers.
The advantage of this solution is a higher speed of computation:
1 solution (3 angles) per second with an 8 bit - computer. (Z80).

6.2 Iterative Solution

In this solution the actual receiver coordinates are not determined. The angle data are calculated directly. Each calculation starts with a known previous helmet position e.g. zero position. Assuming a new position the minimum of deviation - based upon actual transmission times - is determined by a lot of iterative steps (up to 15) using the methods of Davidon-Flatcher-Powell (DFP).
The advantages are high flexibility in the number of measurement paths and very good accuracy.
The disadvantage is a significantly higher computation time.

More recently a system of linear equations was developed by linearizing the expression for the deviation.
Using this later method results in a vast improvemnent of convergence and computation speed.

7. State of work: accuracy and speed

To prove the state of work with the prototype line-of-sight locator (LOSL) accuracy measurements have been made on a lifesize cockpit mock-up.
The 3-axis computer controlled platform (ACP) - developed at the same time - was used to position the helmet and receivers with an accuracy of $< 0.1^{\circ}$ into a programmable angle position.
In a second step the line-of-sight locator had to determine these angles. Afterwards the programmed (ACP) and measured (LOSL) angle data have been compared.
The result is an **accuracy of $<0.5^{\circ}$ achieved by this prototype** line-of-sight locator.

Using an 16-bit computer (MC 68000) ca. 20 solutions per second (each consisting of 3 angles) are available for output to the platform.

The dynamic operation of the line-of-sight locator and 3-axis platform too has been tested within the cockpit mock-up.

The next step is to develop and manufacture a preseries line-of-sight locator. In parallel a supplementary angle error correction is being considered .