

A FLIGHT TEST METHOD FOR PILOT/AIRCRAFT ANALYSIS

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1. INTRODUCTION

In high precision flight manoeuvres a pilot is a part of a closed loop pilot/aircraft system. The assessment of the flying qualities is highly dependent on the closed loop characteristics related to precision manoeuvres like approach, landing, air-to-air tracking, air-to-ground tracking, close formation flying and air-to-air refueling of the receiver.

The object of a research program at DFVLR is the final flight phase of an air to ground mission. In this flight phase the pilot has to align the aircraft with the target, correct small deviations from the target direction and keep the target in his sights for a specific time period (Fig. 1).

To investigate the dynamic behaviour of the pilot/aircraft system a special ground attack flight test technique with a prolonged tracking manoeuvre has been developed (Fig. 2).

By changing the targets during the attack the pilot is forced to react continuously on aiming errors in his sights. Thus the closed loop pilot/aircraft system is excited over a wide frequency range of interest, the pilot gets more information about mission oriented aircraft dynamics and suitable flight test data for a pilot/aircraft analysis can be generated.

This report includes

- general description of the test equipment
- input signal design
- flight test program
- first results of an evaluation.

2. TECHNICAL ARRANGEMENT

The test set up of the Ground Attack Target Equipment (GRATE) shows that it consists of onboard and ground systems (Fig. 3). Main part of the ground system are nine light targets.

The overall arrangement of the ground system (all lamps switched on) is shown in Fig. 4 from the point of view of a pilot during a simulated attack.

Each target is a lamp cross with eight halogen lamps switched on and off by a microprocessor according to the signal received via connecting cables from the telemetry ground station (Fig. 5).

3. INPUT SIGNAL DESIGN

When the pilot has to align the aircraft to light targets switched on and off at different positions on the ground, a multi-step input signal to the pilot/aircraft system is generated. This input signal should be designed to obtain suitable flight test data for system identification.

3.1 General Characteristics

A period of a step signal which changes its value in accordance with constant time intervals Δt is shown in Fig. 6.

The power spectrum of the signal indicates the frequency ranges of the system which can be analysed.

The spectrum $|Z(\omega)|^2/T$ is a function of the interval Δt and the amplitudes v_i and consists of two factors.

The first factor $2 \Delta t (1 - \cos \Omega)/\Omega^2$, where $\Omega = \omega \Delta t$, is a function of the duration of the interval Δt and the frequency ω and is not affected by the switching amplitudes v_i . Changing from the power spectrum to the amplitude spectrum, the root must be taken, resulting in a clearer diagram for the first factor (Fig. 6).

In dependence on Δt amplitude values vanish at equidistant frequencies $\Omega_N = 2 k \pi$ ($k = 1, 2, 3, \dots$). At these frequencies the power spectrum disappears, independently of the second factor.

The peaks of the functions shown steeply decrease with increasing frequency Ω . Since the second factor is periodic with $\Omega = 2\pi$ the drop of the amplitude spectrum at higher frequencies cannot be prevented by a special selection of the amplitudes v_i . These characteristics of the spectrum counteract the effort of generating signals with an approximately constant spectrum. But the possibilities existing within the limits discussed should be utilized.

For the tests the effort should first be made to keep the duration of the interval Δt as small as possible. This expands the region to the first null towards higher frequencies.

In the flight test, limits based on the characteristics of the pilot/aircraft system are set to the selection of short interval periods Δt .

If the change-over times are too short, the pilot is not able to perform the attack. On the other hand interval periods which are too long are meaningless since the alignment of the aircraft is followed by an approximately steady-state process which contains only few information and the pilot is not motivated to pay full attention.

The range of meaningful interval periods was determined in the test and is approximately

$$2.25 \leq \Delta t \leq 3.15.$$

Step signals with different duration of intervals Δt can be applied in the tests to alleviate the effects of the nulls to a certain extent.

3.2 Input Signals for Ground Attack

In order to be able to investigate various parts of a pilot model, they are subjected to separate tests.

To investigate the pilot characteristics with respect to compensation in longitudinal motion an excitation by setting up the lamps in longitudinal direction is provided (Fig. 7).

The lamps are switched whilst the aircraft flies along a predetermined flight path.

A computer program was generated for selecting suitable signals from the multitude of all possible input signals. It supplies a predetermined number of signals $z(t)$ which

- change over to a new value after each interval Δt
- exceed a minimum limit for the standard deviation to cause sufficiently large jumps in pitch angle
- do not exceed a predetermined size of visual angle steps (1°).
- have a power spectrum of the visual angle ϵ_x which is constant within the frame of possibilities.

The step signal in Fig. 7 was determined by this program. Its spectrum is also shown in the figure.

To investigate the pilot characteristics with respect to compensation in lateral direction an excitation by setting up the lamps in lateral direction is provided (Fig. 8).

Although this arrangement also generates an excitation in the longitudinal motion, the excitation in the lateral motion remains dominant.

The input signals used in the test were also determined by the program mentioned above.

For the investigation of the overall pilot model an apparently arbitrary excitation in any direction is required. A favourable arrangement is given if nine lamps are set up in a nine pins game-like pattern (Fig. 9).

Each lamp is provided with a position number as specified in the Figure. It is switched on when the signal $z(t)$ has the value of the position number.

From the signal $z(t)$ the x- and y-position number can be derived. These signals $z_x(t)$ and $z_y(t)$ can be treated in the same manner as the input signals previously discussed.

Also for these tests a computer program was written to generate input signals which have power spectra of the visual angles ϵ_x and ϵ_y which are constant within the frame of possibilities.

4. FLIGHT TEST PROGRAM

A flight test program was performed utilizing a modified Alpha-Jet with a multi mode control system.

A total of 10 flights with 183 attacks were executed. The test pilots rated the task to be well suited for evaluating air-to-ground handling qualities. Pilot comments were documented using the well known Cooper Harper rating scale along with related scales for turbulence, pilot induced oscillation susceptibility and buffet. Good correlation was obtained between pilot comments and ratings and the apparent behaviour of the system.

5. EVALUATION OF FLIGHT TEST DATA

The evaluation of the flight test data has been concentrated on the investigation of tracking performance parameters. In particular the initial line-up time was evaluated. For these investigations flight test data were measured from head-up display camera film including position of piper and the illuminated lamp.

In the time histories of an example shown in Fig. 10 the steps in pitch and azimuth angle when the lamps are switched, and the changes initiated by the pilot in order to track the targets are clearly visible.

The star like pattern in the cross plot of target minus piper position shows four loops which correspond to the four steps of the light signal.

The time histories of these four sequences can be treated as four isolated characteristic motions with different initial conditions of the pilot aircraft system. When the light jumped in the negative direction of pitch or yaw, the subsequent time histories of the deviations in pitch or yaw were turned over (multiplied by -1) to deliver a characteristic motion with a positive initial condition.

The mean values calculated from the four characteristic motions and curves of limits of confidence are shown in Fig. 11.

Thus the influence of noise on the time histories can be reduced.

The characteristic motions of pitch and yaw were used to compute a mean radial deviation which decreases over time.

The time up to the moment, when the mean radial deviation passes the value of 3 mrad was determined and increased by 10 %. This result was defined to be the initial line-up time.

Fig. 12 shows the dependence of this time to the serial run number of a flight and the excitation mode.

Each symbol is a result of one attack run. Two approaches signed in the diagram were affected by windshear effects and resulted in comparatively large initial line-up times. Therefore they should be unconsidered in further contemplations.

In the diagrams a slight increase of the initial line-up time with respect to the serial run number is visible.

The time to align the aircraft after a vertical step of the target is shorter than after lateral or combined displacements.

In general the time to line-up the aircraft is very short and did not exceed the value of 1.5 sec.

Further investigations will include a flight path reconstruction utilizing camera and tape recorded data. Tracking performance parameters will be determined and an identification of the pilot/aircraft system will be initiated.

For the enlargement of the data base additional flight tests were performed.

6. CONCLUSIONS

A flight test method was presented that has some advantages compared to previous methods.

- The pilot is engaged in an operational task of a flight phase, which is very important for military missions.
- Input signals act directly on the pilot, no modification in the control system of the aircraft is necessary and the pilot can immediately interrupt the test.
- The applied input signals are predesigned and reproducible in the flight tests. They can be adapted to the manoeuvrability of the pilot/aircraft system. Thus the pilot and the aircraft can be excited up to high frequencies.
- The test method is well accepted by test pilots and proved very effective for flying quality assessments by pilot comments and ratings.
- The input and output signals of all subsystems can be measured.
- The data are suitable for pilot/aircraft analysis.
- A preliminary evaluation of test data was concentrated on the determination of initial line-up times. The dependence of the results on windshear effects, serial run number of a flight, and excitation mode was discussed.

Further investigations will be concentrated on determining more tracking performance parameters and on system identification of pilot/aircraft systems.

7. REFERENCES

- Onstott, E.D. Prediction, Evaluation and Specification of Closed
Faulkner, W.H. Loop and Multiaxis Flying Qualities.
 AFFDL-TR-78-3 (1978)
- Buchacker, E. Flight Testing an Alpha Jet with a Direct Side Force
Koehler, R. Control System in the Air-to-Ground Role.
Meyer, H. Flight Test Symposium 1984, CFB Cold Lake, Medley,
Skudridakis, J. Alberta (Canada), 11./12.04.1984.
- Koehler, R. Design and Implementation of Input Signals for Identification of Pilot/Aircraft Models.
 ESA-Translation of DFVLR-FB 84-08, EA-TT-880.

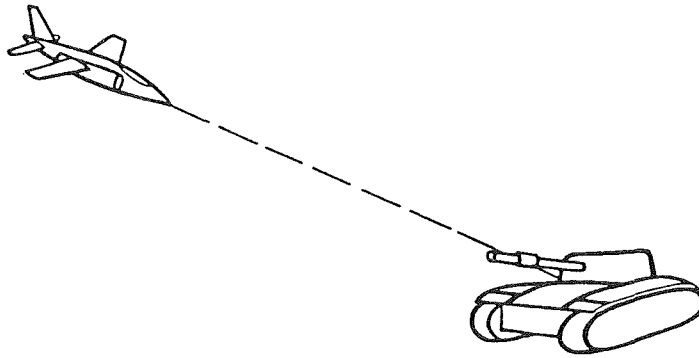


Fig. 1 Operational Air to Ground Tracking Task

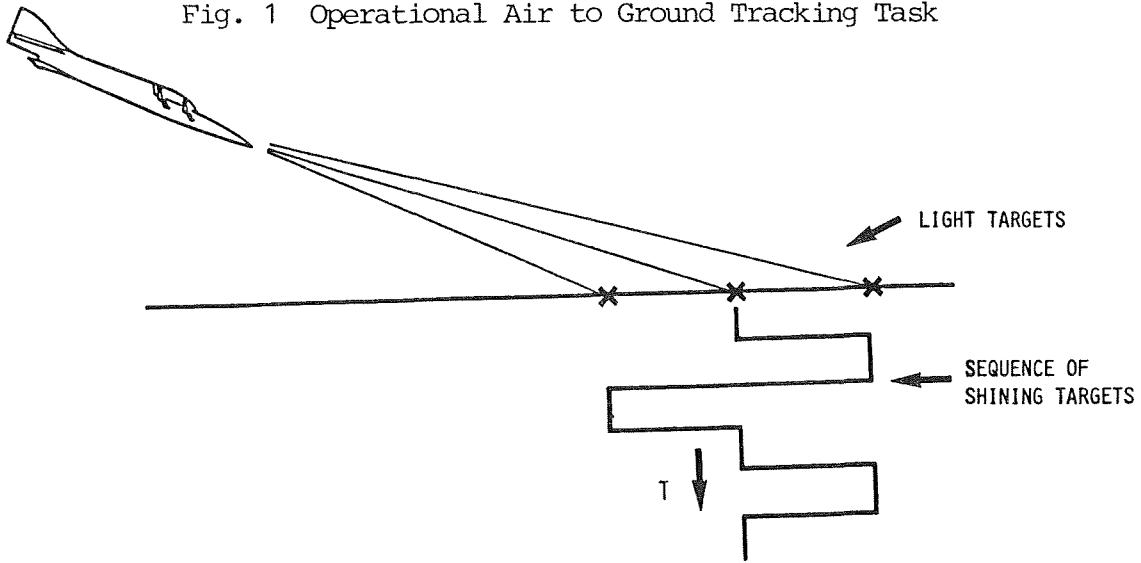


Fig. 2 Modified Air to Ground Tracking Task

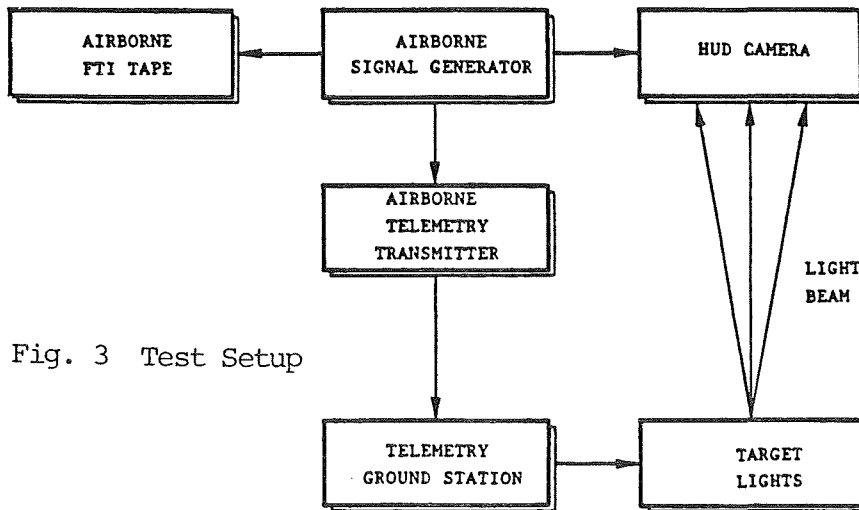


Fig. 3 Test Setup

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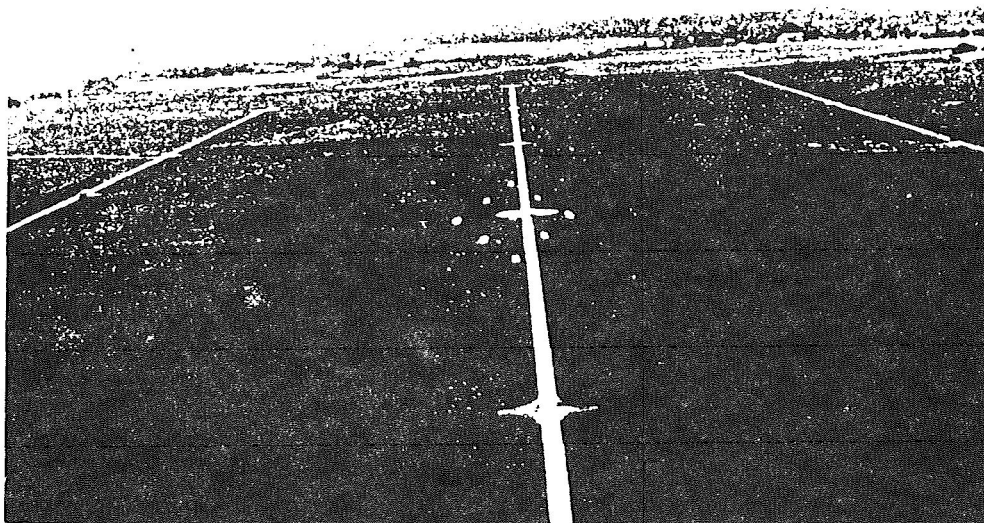


Fig. 4 Arrangement of Target Lights on Ground

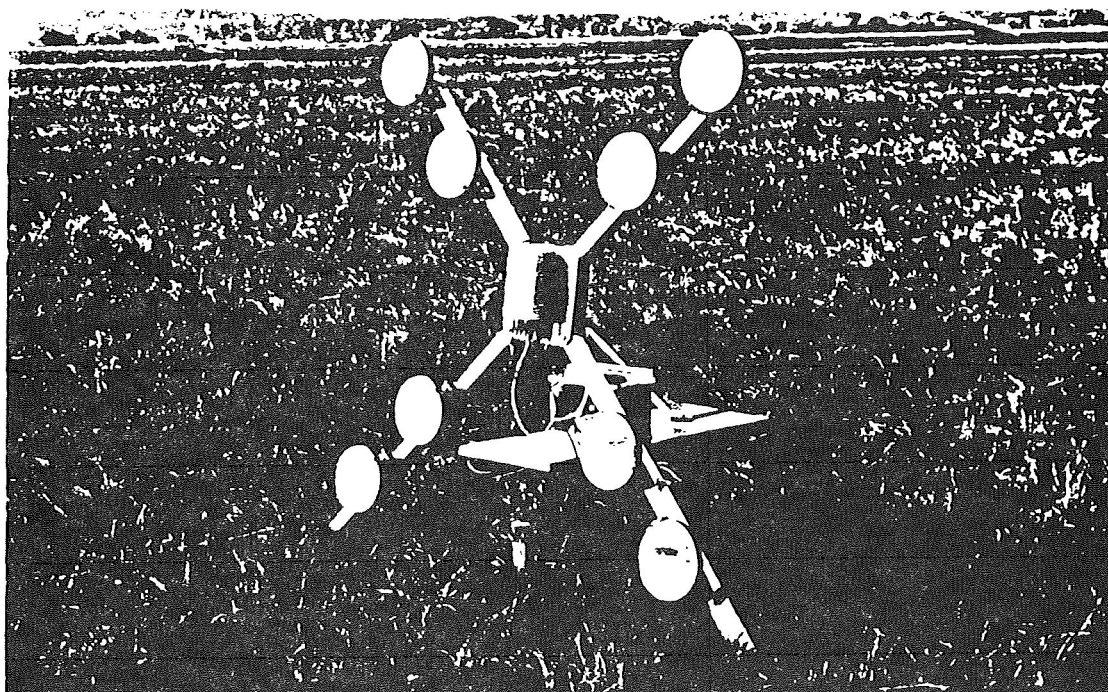
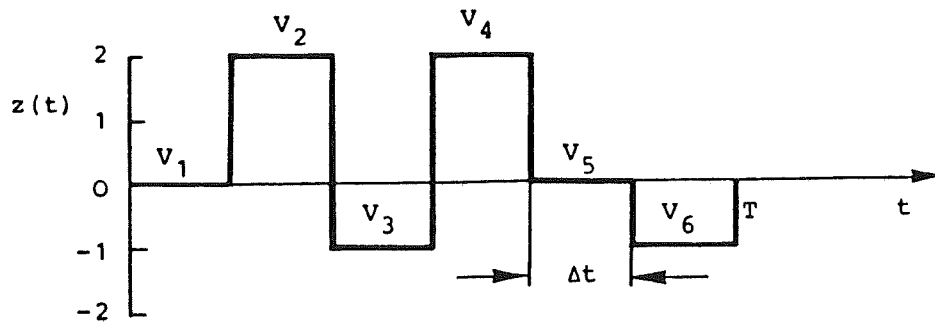


Fig. 5 A Lamp Cross



$$\frac{|Z(\omega)|^2}{T} = 2\Delta t \frac{1-\cos\Omega}{\Omega^2} \left[\frac{1}{N} \sum_{i=1}^N v_i^2 + \frac{2}{N} \sum_{i=1}^{N-1} \cos i\Omega \sum_{j=1}^{N-i} v_{i+j} v_j \right]$$

with $\Omega = \omega\Delta t$

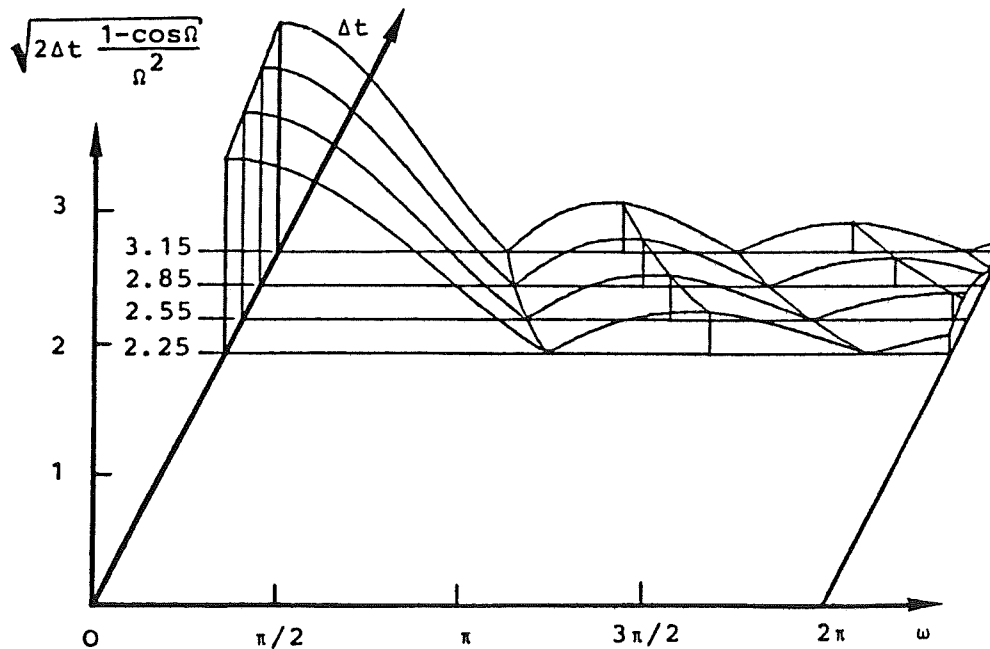


Fig. 6 Power Spektrum of a Multi Step Input Signal and a Presentation of the Dominant Factor

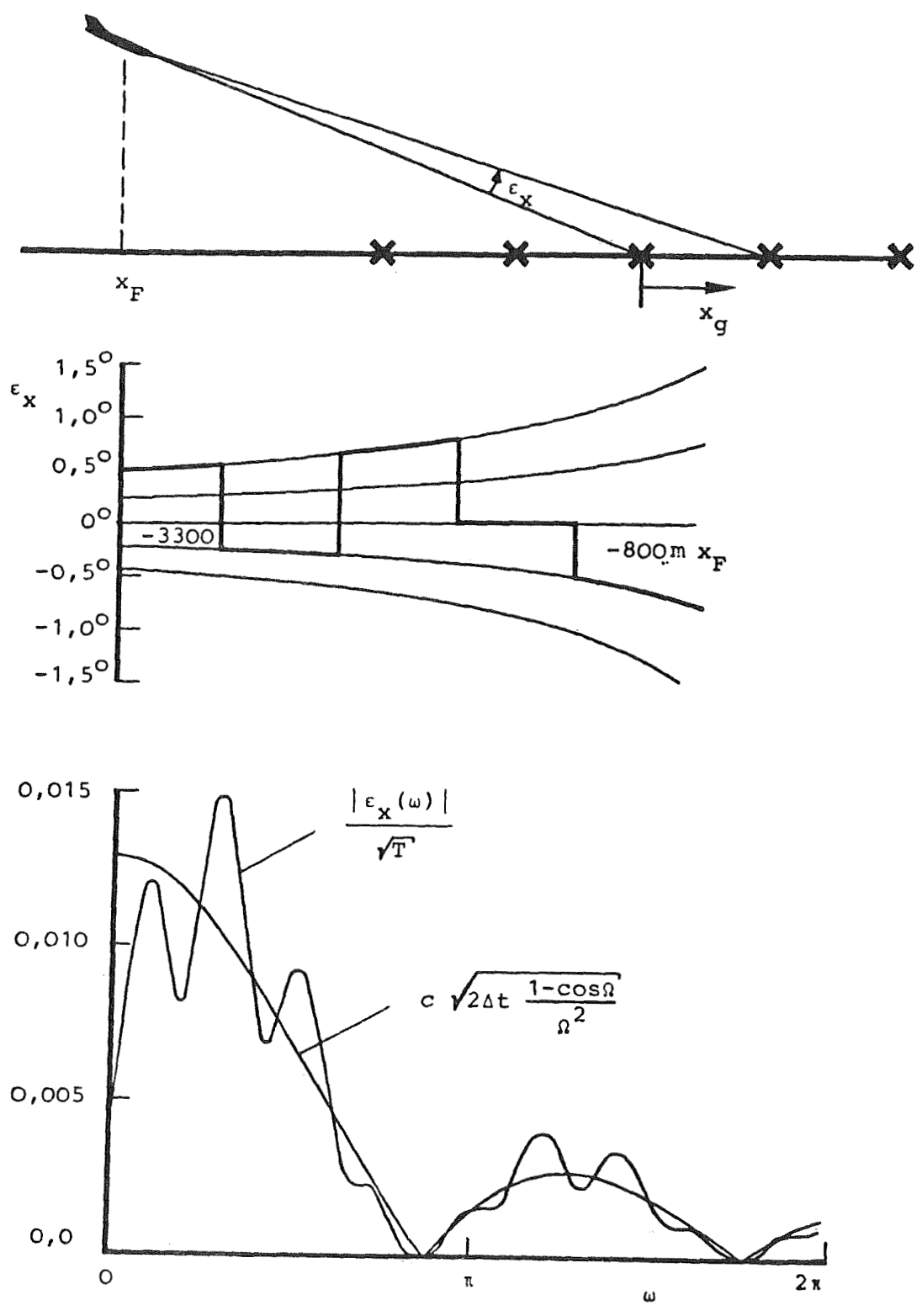


Fig. 7 Time History and Spectrum of Line of Sight Angle $\epsilon_x(t)$
 $(\Delta t = 2.25 \text{ sec})$ 35.10

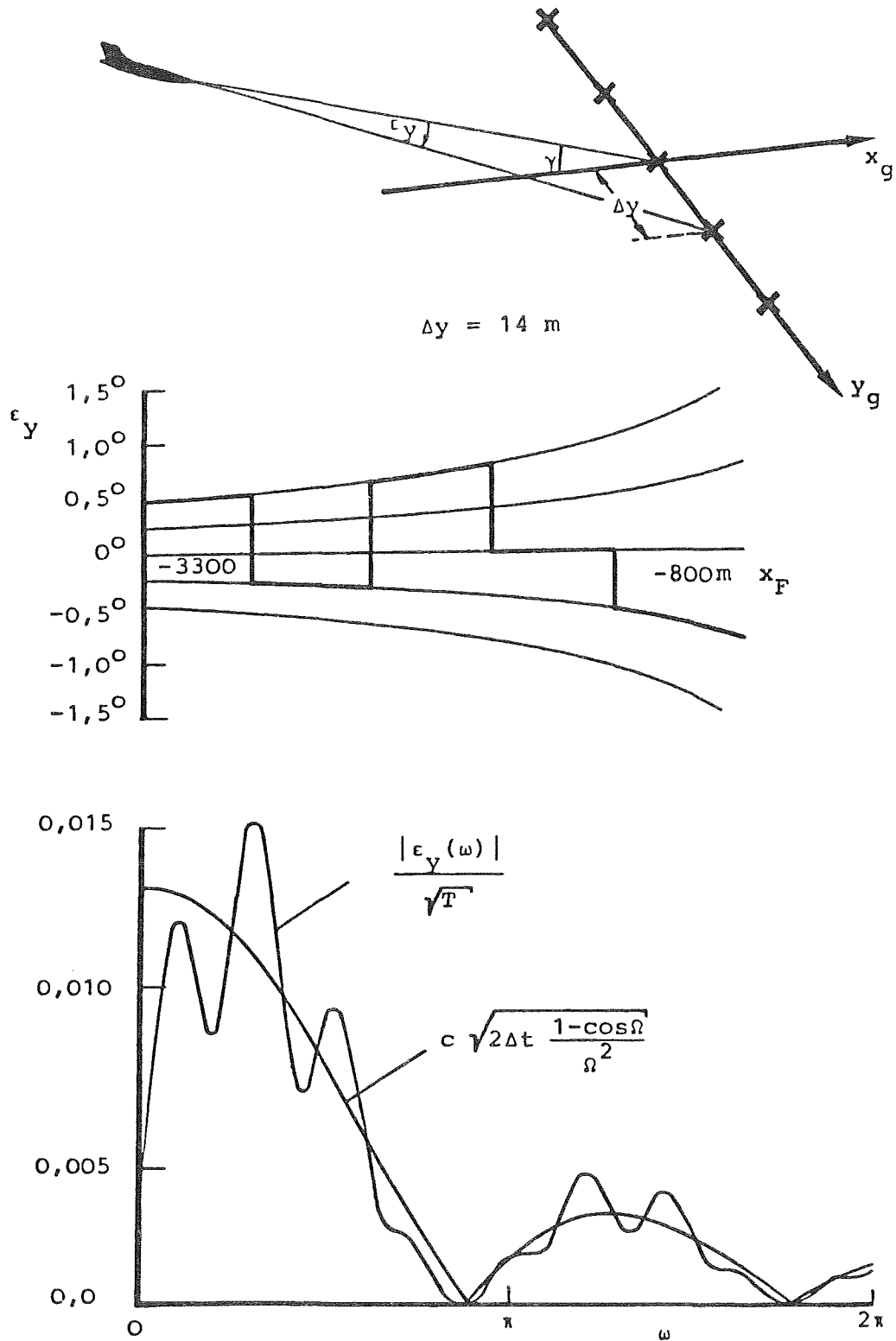


Fig. 8 Time History and Spectrum of Line of Sight Angle $\epsilon_Y(t)$
 $(\Delta t = 2.25 \text{ sec})$

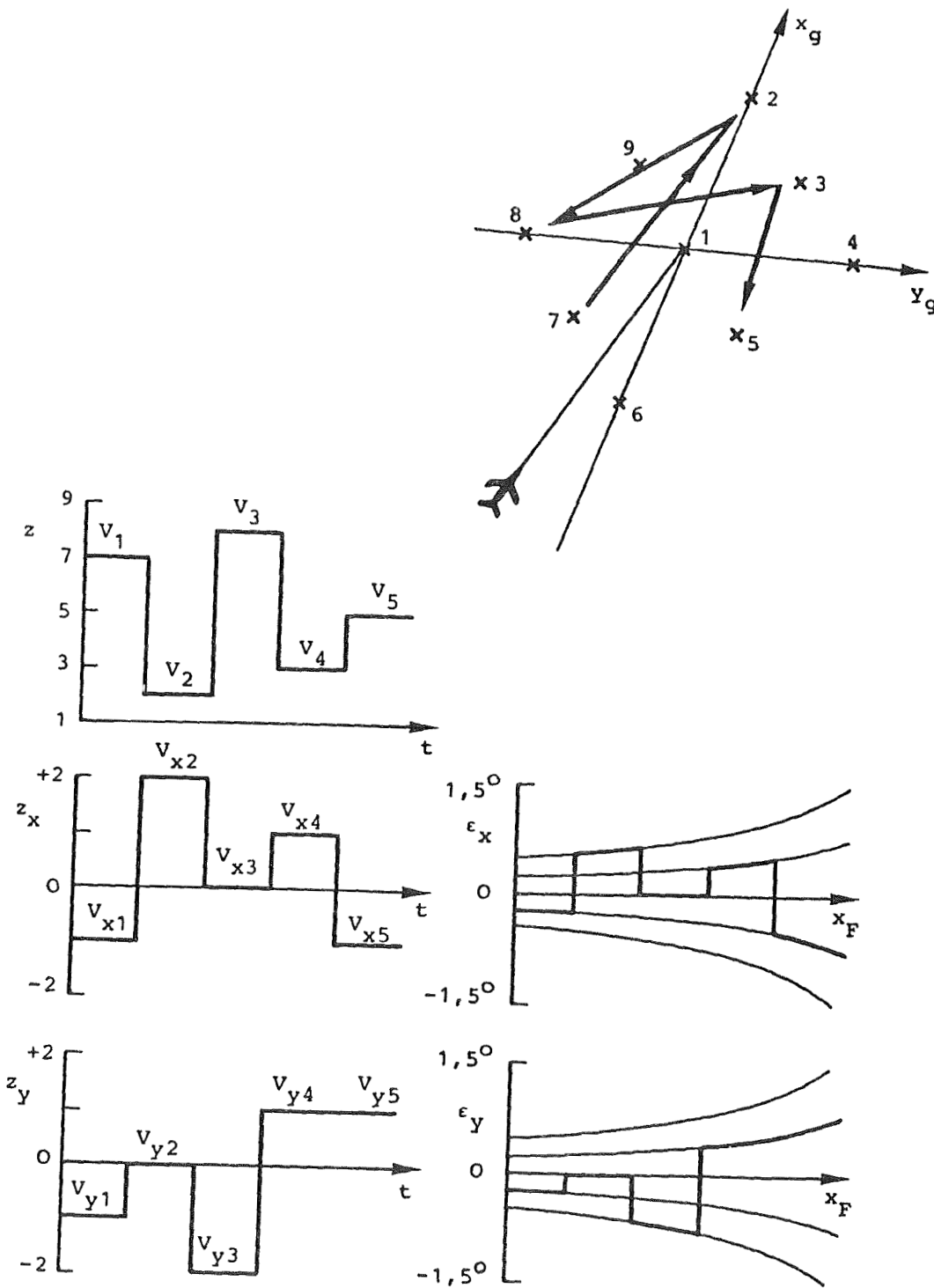
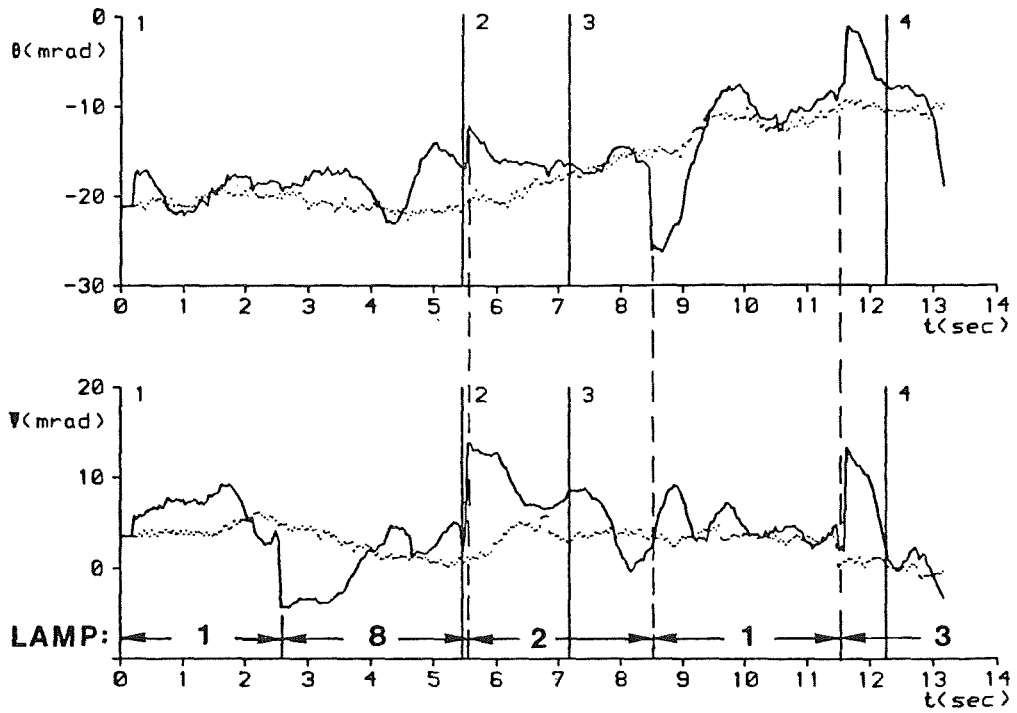
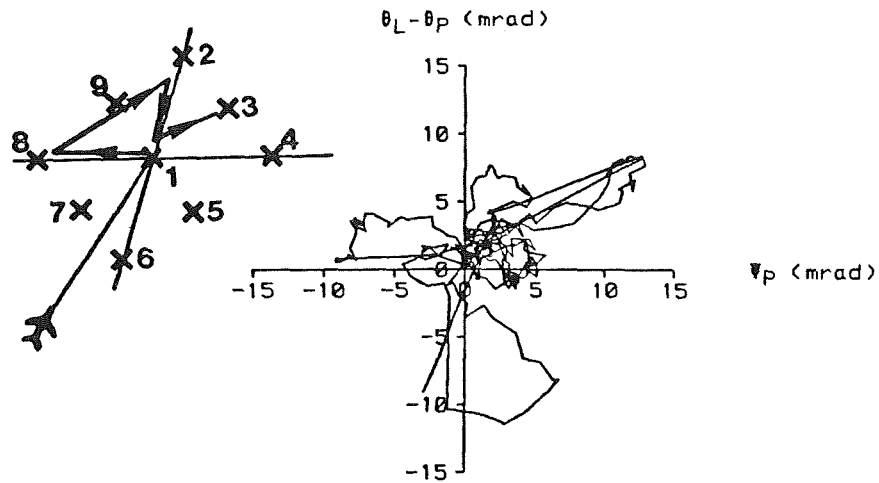


Fig. 9 Input Signals of the Combined Pattern



TIME HISTORIES OF FILM DATA
 ——— LIGHT - - - - PIPPER
 |³ RANGE OF PIPPER SYMBOL



AIMING ERROR

Fig. 10 Plots of Film Data

FLIGHT FILM RUN
 786 1 4

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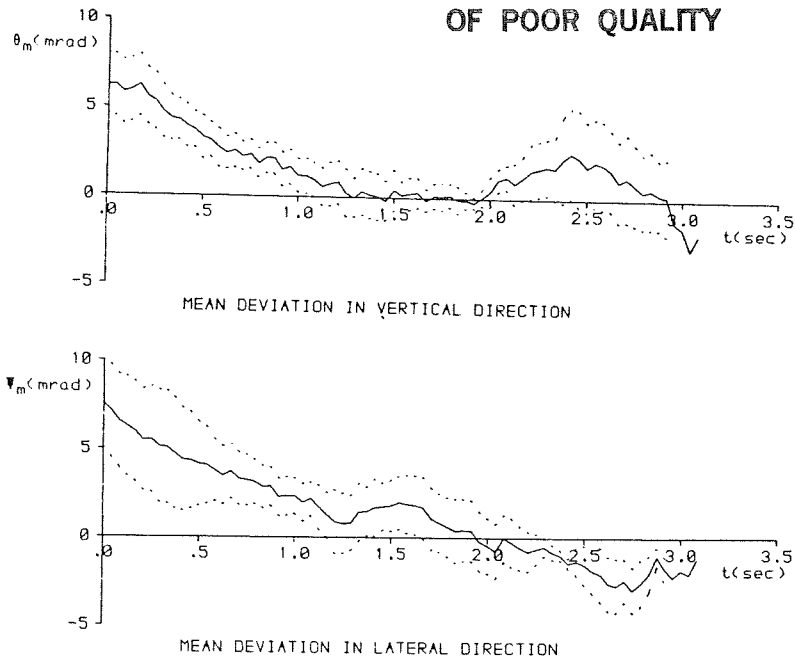


Fig. 11 Time Histories of the Characteristic Motions from Fig. 10

— Mean Values
- - - Limits of Confidence

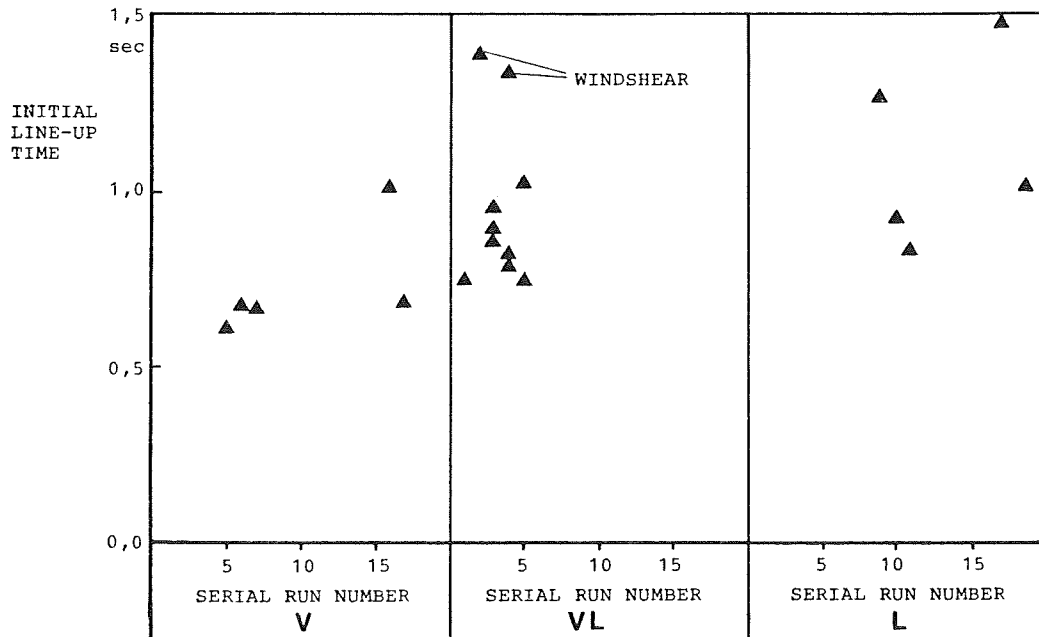


Fig. 12 Initial Line-Up Time Evaluated from Camera Data
V Vertical, L Lateral, VL Vertical and Lateral Excitation