SIXTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

Paper No. 56

FLIGHT TESTS AND STATISTICAL DATA ANALYSIS FOR FLYING QUALITIES INVESTIGATIONS

K. Sanders
H.-J. Pausder
D. Hummes

Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V., Institut für Flugmechanik
Braunschweig, Germany

September 16 - 19, 1980

Bristol, England

THE UNIVERSITY BRISTOL, BS8 1 HR, ENGLAND

FLIGHT TESTS AND STATISTICAL DATA ANAYSIS FOR FLYING QUALITIES INVESTIGATIONS

K. Sanders
H.-J. Pausder
D. Hummes

Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V., Institut für Flugmechanik
Braunschweig, Germany

Abstract

The evaluation of helicopter flying qualities means to asses the fulfillment of presently valid stability and controllability criteria. Due to the extension of the helicopter mission spectrum the application of these evaluation methods leads to difficulties, because mission oriented handling qualities requirements are, in general, not taken into account. For the user of a helicopter, however, it is of main interest, how the desired mission can be performed. Therefore a comprehensive mission criteria evaluation is only possible, when the influence of all subsystems together with pilot ability are considered.

In the DFVLR, studies were conducted, to evaluate flying qualities by analyzing pilot ratings and statistical flight mechanical data. Flight tests, using a BO 105 helicopter were conducted in specific flight conditions as parts of a given mission.

The low airspeed region is of high interest for the military flight mission considered. Therefore, the first tests were defined and performed for hovering flight. The flight condition was called 'Hovering Tracking', where the pilot had to align the helicopter with a defined target in order to minimize the tracking error.

In a second flight test program the NOE-flight was investigated. The problem was about flying around or over an obstacle (Slalom, Dolphin).

These flight tests have been carefully defined in order to provide the basis to fulfill tactical demands as well as to allow a statistical data analysis. In particular, statistical requirements like a sufficient number of test pilots and multiple repetition of the tests were fulfilled. The test method is discussed and the flight tests performed are described in detail.

Flight test data recorded includes all essential flight mechanical data as well as deviation of target and helicopter position. The statistical analysis of the flight test data based on mean and root-mean-square values, probability density distributions, mean crosses and variances. In addition, steady states, continuous movements and reversals were calculated, using the time histories of the tests.

Representative results of the statistical analysis are presented in diagrams to confirm the approach described. Aspects of correlations between task performance, control activity and pilot opinions are discussed.

Notation

CAP_{Amp}	Control activity parameter - amplitude mm/mm
CAP_{Dyn}	Control activity parameter - dynamic sec/sec
G_{max}	Max. gross weight, N
G_{min}	Min. gross weight, N
H_{IGE}	Altitude in ground effect, ft
H_{OGE}	Altitude out of ground effect, ft
TEP_{Amp}	Tracking effectiveness parameter-amplitude, deg
TEP_{Dyn}	Tracking effectiveness parameter-dynamic, sec/sec
T_{cm}	Time of continuous movements, sec
T_{ss}	Time of steady states, sec
V	Flight velocity, kt
V_T	Target velocity, km/h
V_W	Wind velocity, kt
x_T	Azimuth tracking error, deg
y_T	Elevation tracking error, deg
δ_{TR}	Pedal movement relative to full throw
δ_x	Longitudinal stick movement relative to full throw
δ_y	Lateral stick movement relative to full throw
σ	Standard deviation

1. Introduction

In recent years, the task spectrum of helicopter has been considerably expanded, especially in the military range. In addition to an expansion of the higher velocity range, the parts of hovering and low velocity flight are increased by tactical demands to 50 percent of the total flight time. At the same time difficulties result from the technical progress of the helicopters in so far as the existing criteria of the valuation of controllability and stability are highly unsatisfactory for the flying qualities of new helicopters.

For the user of a modern helicopter, the problem is not only the evaluation of the general handling qualities. Very interesting is the question of the fulfillment of a set mission or of mission elements. Such a mission oriented evaluation can only be performed in relation to the pilot's ability and the inclusion of all functions of the helicopter. This also includes the pilot information-, pilot flight control- and augmentation systems.

2. Method

At the DFVLR-Institute of Flight Mechanics a flight test program was planned with the aim to develop a method which allows a mission oriented evaluation. Figure 1 shows the general procedure of this method.

By this method carefully chosen flight conditions are investigated. The selection ensued the repetition of the flight tests to make possible the performance of a statistical analysis. This includes a strict observance of the tactical demand. In the evaluation, objetive data like statistical values of flight mechanical variables, as well as subjective ratings given by the pilots are taken into account. As a result, parameters were established for the quantitative evaluation about the fulfillment of the given task. These parameters represent the basis for further investigations to determine the design parameters of a helicopter.

3. Flight Tests

To investigate mission oriented handling qualities of helicopters, the DFVLR designed a flight test program which is partly completed. The flight tests were done on the DFVLR testbed BO 105-S 123 (Figure 2).

Starting from the tactical concept of German Anti Tank Helicopter (PAH) the mission was divided into three parts, terrain avoidance, NOE-flight, and weapon delivery. A subdivision of mission elements leads to special tasks which can be accurately defined for the flight tests.

The main part of hovering and low velocity flight for the anti tank mission and the connected high priority, led at first to the investigation of the mission element 'Weapon Delivery'. The task for the pilot was to align the helicopter in hovering flight with the target (Hovering Tracking). In a second test program flight tests were performed in the area of NOE-flight. For these tests the pilot had to fly around or over obstacles (Slalom, Dolphin).

3.1 Hovering Tracking

In co-operation with military offices which are responsible for the tactical demands the task 'Hovering Tracking' was defined. The primary task was to align the helicopter, in hovering flight, with the target, in order to minimize the tracking error (Figure 3). The secondary task for the pilot was to keep to a set altitude and a defined position.

The target was represented by a source of light (halogen lamps with 2 kW power) mounted on a lorry. This vehicle was located at a distance of 2000 meters from the hover position of the helicopter. Additionally, a lateral target motion could be simulated by driving nearly 1000 meters on a road.

The measuring equipment contained a TV-camera, mounted in the cockpit in the line of sight of the pilot and a video recording system. The target was tracked by the camera. The transmitting to the ground station was ensued by television. There an on-line tracking of the target deviations was performed to get tracking error data. The deviations in the position of the helicopter were controlled by a TV-ground-camera which was installed under the hover position and fixed on the helicopter.

For the evaluation of the tests, the following flight mechanical data was recorded by a measuring equipment mounted in the cargo compartment of the helicopter:

- translatory accelerations
- angular velocities
- attitudes
- flight control movements measured by potentiometers mounted on the control sticks
- radio altitude.

The spectrum of test configurations was achieved by variation in the following test variables:

- hovering height	$H_{IGE} = 15$ ft,	$H_{OGE} = 60$ ft
- gross weight	$G_{min} = 19000$ N,	$G_{max} = 22000$ N
- target velocity	$V_T = 0$ km/h	$V_T = 40$ km/h and
- wind velocity	$V_W < 5$ kt (frontwind	± 45 deg)
	$V_W > 15$ kt(tailwind	± 30 deg).

To obtain a sufficient amount of data for the statistical analysis the tests were performed with five pilots. Three pilots were test pilots, two were operational pilots in the German Army. All the pilots were experienced in flying the anti tank mission. Because of lack of time pilot No. 1 could only fly about 30 per cent of the test program. Therefore, for the evaluation only the pilots 2 to 5 were taken into consideration.

Each test was conducted by flying five isolated runs of the same kind, each taking 60 sec. Before starting a test series all pilots were fully conversant with the task. Sufficient time was given to them to train for the task with the helicopter. These preliminary tests were necessary with regard to the fulfillment of the secondary task, so that the pilots could note the surrounding area for the observance of their position.

Between each run, the pilot was led back to his start point with the aid of the TV display. If the deviations exceeded the boundaries of the ground camera, the runs were repeated, because the task was not fulfilled and furthermore, difficulties could occur in tracking. As a result of the flight tests all data was available in time synchronized form, sampled at about ten times the highest frequency of interest (2,5 Hz). This was useful as the sample frequency of 25 Hz was half the video signal frequency of 50 Hz.

After each flight (2 test configurations), the pilot was asked to answer a questionnaire, containing questions concerning

- the handling qualities of the helicopter for the task
- the pilot stress for the task
- the task performance.

With a rating scale, which corresponded to the Cooper-Harper scale the pilots were able to make quantitative ratings to the questions (Figure 4). The pilots were requested to relate their ratings only to the test performed, and not to their prejudice.

3.2 Slalom/Dolphin

The second test program contained tests in NOE-flight. For this a tract was built which consisted of two obstacles with a separation of 350 metres (Figure 5).

For the slalom tests the pilot had to choose a flight path which minimizes the duration of stay in a lateral corridor between 5 and 10 metres beside the obstacles. The height was given as 30 ft. This, as well as the azimuth had to be corrected between the obstacles.

In the test description 'Dolphin' was requested to minimize the duration of stay in a vertical corridor between 15 and 30 ft above the obstacles. Here also, the pilot had to return to his original height of 15 ft between the obstacles.

The beginning of the test tract was 200 metres in front of the first obstacle, the end of the test tract was 200 metres behind the second obstacle. In this way one could fly this measuring course in both directions without changing the tract. The measuring signals were transmitted to the ground station by telemetry. In addition to the flight mechanical data which was also measured at 'Hovering Tracking', the position of the helicopter was received and recorded with special measuring equipment.

The spectrum of test configurations was achieved by variation of gross weight and forward velocity. This resulted in the following test variables:

G_{min} = 17460 N, G_{max} = 21000 N
V = 40, 60, 80 and 100 kt.

In the flight test program six pilots were involved. Besides the DFVLR-pilot, three test pilots and two operational pilots of German Army took part in the tests. Here also, the pilots had to answer a questionnaire which was similar to that in the 'Hovering Tracking' tests.

4. Data Analysis

The measured and recorded data of the 'Hovering Tracking' tests not only shows significant differences between the pilots but also between the test configurations. In Figure 6 the azimuth and elevation tracking errors as well as control movements of longitudinal stick and pedals are crossplotted for a single run of different test configurations. Additionally, configuration A is plotted for all pilots. The flight test configurations 'Moving Target' (C) and 'Tail Wind' (D) clearly show an increasing control activity as well as increasing target deviation. Whereas this is feasible, the significant differences between the pilots are remarkable. The aim of the study was to cover the information contents of the data into a few parameters. For this, a statistical analysis of the flight tests is a suitable tool.

Although the duration of each run was 60 seconds, only 40 seconds were evaluated. So a sufficient space of time for evaluation was available if runaways or other disturbances were to occur. The statistical values were calculated for each single run and then averaged for the five runs of the test configuration.

By means of a confidence value of 95% probability, established from the t-distribution it was checked wether the runs exceed the confidence interval. These runs were not taken into consideration in the further investigation.

The standard deviation of the tail rotor control is drawn for the test group 'Hovering Tracking, Front Wind' as an example in Figure 7. For each single test configuration the standard deviation range can be seen as well as the variations of the mean values averaged over the five runs. It can be seen, that it is permissible to use the mean values of the statistical data in the following investigations.

In Figure 8, the averaged probability distribution of the target azimuth angle x_T and the pedal control δ_{TR} normalized to full throw is shown. For pilot No. 2 the distributions are presented for two different configurations. Additionally the probability distributions are shown for two different pilots and the reference test configuration 'Hovering Tracking, Front Wind'.

The tracking signals seem to be normally distributed, whereas the pilots prefer certain tail rotor control positions. The other three flight controls show the same tendency.

In this figure, significant differences can be seen again within the test configurations (upper part of the figure) and within the test pilots (lower part).

The probability distribution curve can be characterized by parameters like standard deviation, maximum, minimum and variances. Increasing complexibility of the task (front wind - moving target - tail wind) results in increased values of standard deviation of tail rotor control and tracking error, which can also be seen as decrease in the gradient of the curve in Figure 8. So it is obivous, that the main efforts should be put into the determination of these values in the statistical investigation.

The contents of the measured signals with regard to the amplitude can be represented by the probability distribution or by the parameters which characterize the distribution. The dynamical behaviour is illustrated in a better way by the probability density distribution. In Figure 9 the probability density distribution curve is shown corresponding to Figure 8. It can be seen from the peeks that the pilots prefer these control levels. The high differences in probability of adjoining control positions explain, that the pilots cross other control positions very fast. Additionally there are significant differences in the dynamic pilot behaviour in the test configurations as well as for one pilot and different tests. These variations can be seen very clearly especially in the diagrams of the control movements.

To get a better insight into the dynamical contents of the signals, certain parameters were defined in the time domain in another statistical analysis. All statistical parameters are listed in Table 1. In Figure 10 for a short time interval the longitudinal control deflection, standardized to full throw, is shown. For explanation of the terms reversal, steady states and continuous movements appropriate marks are made. The changes of direction of the signals are called reversal. Steady states are the time periods during which only limited deviations of the signals occur. Continuous signal changes in one direction are identified as continuous movements. In Table 2 the definitions of the boundaries of these parameters are represented. These definitions were chosen as a result of discussions with the pilots and after examination of the data. The characteristic, already mentioned, that pilots prefer certain control positions, is explained in Figure 10 very clearly by the time record of the flight control.

5. Data Evaluation

To carry out a data evaluation, it is necessary, to take into account the pilot ratings. As above mentioned, the pilots were asked to give ratings for the handling qualities of the helicoper, the pilot stress and the task performance. The relations between the pilot ratings 'Handling Qualities' and 'Task Performance' and the pilot rating 'Stress' is shown in Figure 11. It can be seen, that the valuation of task performance and stability is equal to the valuation of the stress. The maximum deviation is two rating points. This is permissible because the steps of the rating questionnaire are one point. It seemed to be of no use, to further subdivide the rating scale, particularly because the pilots were not able to give a more exact rating.

Only the valuation of the controllability shows no direct relation to the pilot rating 'stress'. It seems, that the pilots did not only consider the relation to the appropriate task but also rated their experience with the helicopter. The pilot rating 'stress' was used to determine the statistical parameters which are important for the evaluation.

The determination of the correlation factor is a method used to show the relations between the statistical parameters and the pilot rating and relations among the parameters themselves. The correlation factor gives a qualitative statement about a linear relation between two values. Fundamentally the range extends from +1 when the relation is direct, to -1 when the relation is indirect. No relation between two parameters exist, if the correlation factor is zero. To get a significant result from the correlation factors, it is necessary that the correlation factors exceed a certain value. This boundary, determined by the t-distribution, is 0.497 for ten test configurations. In Figure 12 the correlations of these parameters to the pilot rating 'stress' exceeding this boundary are shown. Only this data was taken into account for the data base of the 'Hovering Tracking' test.

The parameters with good correlations were

- standard deviations σ
- part of the steady state time T_{ss} on the test time, and
- part of the continuous movement time T_{cm} on the test time

for the following measurement signals:

- longitudinal stick control δ_x
- lateral stick control δ_y
- pedal control δ_{TR}
- azimuth tracking error x_T, and
- elevation tracking error y_T.

The correlation factors were determined for the particular pilots and then averaged. It is not possible to do a further data reduction, as shown in the correlation matrix (Figure 12) because the pilots are weighting the flight controls and target deviation parameters in a different way. So the pilot rating is influenced by different parameters.

In Figure 13 the standard deviation as a function of the ratio $\frac{T_{cm}}{T_{ss}}$ is shown for the tail rotor control and the lateral target deviation. It is evident that the pilots have different ways of using the controls. Pilot No. 2 allows a high deviation of tail rotor control and a small dynamic content. On the other hand the control activity of pilot No. 4 is considerably higher, the standard deviation is smaller. For the target azimuth angle pilot No. 4 has both, a smaller standard deviation as well as remaining more calmly on target than pilot No. 2. The standard deviation range of pedal control of pilot No. 3 has nearly the same value as for pilot No. 2. The control activity on the other hand is very small. So he does not remain very calmly target and allows a high standard deviation in the tracking error.

These examples show the different kind of interpretation of the tasks by the pilots with respect to accuracy of the execution.

As already mentioned, a further data reduction, as given in Figure 12, is not possible. So it is necessary to find a useful combination of these parameters. This leads to parameters, indicating the performance of the pilot/helicopter system (Tracking Effectiveness Parameters - TEP) and parameters describing the control behaviour of the pilot for the 'Hovering Tracking' task (Control Activity Parameters - CAP). The definitions are as follows:

- Tracking Effectiveness-Amplitude

$$TEP_{Amp} = \sqrt{\sigma^2_{x_T} + \sigma^2_{y_T}} \qquad (deg)$$

- Tracking Effectiveness-Dynamic

$$TEP_{Dyn} = \left(\frac{T_{cm}}{T_{ss}}\right)_{x_T} + \left(\frac{T_{cm}}{T_{ss}}\right)_{y_T} \qquad \left(\frac{sec}{sec}\right)$$

- Control Activity-Amplitude

$$CAP_{Amp} = \sigma_{\delta_{TR}} + \sqrt{\sigma^2_{\delta_x} + \sigma^2_{\delta_y}} \qquad \left(\frac{mm}{mm}\right)$$

- Control Activity-Dynamic

$$CAP_{Dyn} = \left(\frac{T_{cm}}{T_{ss}}\right)_{\delta_{TR}} + \left(\frac{T_{cm}}{T_{ss}}\right)_{\delta_x} + \left(\frac{T_{cm}}{T_{ss}}\right)_{\delta_y} \qquad \left(\frac{sec}{sec}\right) .$$

The combination of these parameters is shown in Figure 14. The drawn measurement data for each pilot are divided up into the rating groups: satisfactory, acceptable and unacceptable. The boundaries of these ranges are roughly marked by dotted lines. The uncertainty of one rating point which can occur has to be taken into account.

The given rating points for 'pilot stress' are especially influenced by the tracking effectiveness. Increasing values of TEP results in decreasing pilot ratings. This is not only evident for the behaviour in relation to the amplitudes but also for the dynamical contents of the signals. On the other hand, a deterioration of the pilot rating occurs, when the control activity is low and also when it is high. This points to an optimal combination of control activity and tracking effectiveness parameters. An extension of the covered areas can be obtained by flight tests with other types of helicopters to get a broader data base.

The requirements for a helicopter system can be quantified for certain mission elements by the evaluation scales defined in this paper. The defining of boundaries in one diagram leads to the values of the evaluation scales in the other diagrams. In this way, specifications can be estimated at an early stage of a project. In the same way, the evaluation of task oriented flying qualities can be performed.

6. Concluding Remarks and Future Efforts

A new test and analysis technique has been developed at DFVLR and has been proven as a valuable tool for closed loop flying qualities evaluation in a mission oriented environment. This technique, which has been applied to the 'Hovering Tracking' task, selected as a mission element from the German Anti Tank Helicopter mission, is based on statistical analysis methods.

The flight tests 'Hovering Tracking' are described in detail in this paper. To obtain a broad data base, the tests were conducted with five pilots. The pilots were asked to answer a questionnaire giving ratings of handling qualities, task performance and pilot stress for the specific flight test.

A second test series, which has not yet been completely evaluated is briefly described. These tests were conducted with six test pilots.

The statistical evaluation of the 'Hovering Tracking' tests contains the determination of parameters like standard deviations, variances and peak-to -peak values. The dynamical contents of the measuring signals can be represented by terms like steady states, reversals and continuous movements.

By the determination of correlation factors, relations between the pilot rating 'stress' and the statistical parameters were established. By definition of Tracking Effectiveness- and Control Activity Parameters the reduced data could be summarized into a few diagrams. In these diagrams, boundaries for the 'pilot stress' rating groups: satisfactory, acceptable and unacceptable can roughly be established. The pilot ratings point out an optimal combination of tracking effectiveness and control activity.

The evaluation diagrams enable to quantify the task related evaluation of helicopter systems. An overall evaluation of handling qualities of helicopter systems requires additional investigation. For the expansion of the existing data base, equivalent flight tests are planned in Hover- and NOE-flight, using other types of helicopters.

7. References

1. G.E. Cooper, R.P. Harper — The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities. ARGARD Report 567, April 1969.

2. P. Hamel, B. Gmelin, H.-J. Pausder — Ermittlung und Bewertung der Flugeigenschaften des zukünftigen PAH - Vorschlag für ein Flugversuchsprogramm - DFVLR Report IB 154-77/26, Sept. 1977.

3. H.-J. Pausder, B. Gmelin — Flight Test Results for Task Oriented Flying Qualities Evaluation. Paper presented at the 36th Annual Forum of the AHS, May 1980.

4. H.-J. Pausder, K. Sanders — Flugversuche Hovering Tracking. DFVLR Report IB 154-79/5, March 1979.

5. A.L. Edwards — Statistical Methods. New York; Holt, Rinehart and Winston, 1973.

• Max./Min. Values • Peak to Peak Value • Mean Value • Standard Deviation, Variance
• Number of Mean Crossings • Mean Gradient of Mean Crossing • Number of Steady States Per Second • Summed Time of Steady States • Mean Time of Steady States • Max. Time of Steady States • Distribution of Steady State Times • Number of Reversals Per Second • Number of Continuous Movements Per Second • Summed Time of Cont. Movements • Mean Time of Cont. Movements • Max. Time of Cont. Movements • Distribution of Cont. Movement Times

Table 1 Statistical Parameters of Measured Signals

Signals	Minimum of Time	Interval of Amplitude Variation
δ_x	0.2 sec	0.25% of Full Throw
δ_y	0.2 sec	0.375%of Full Throw
δ_{TR}	0.2 sec	0.25% of Full Throw
x_T	0.2 sec	0.2 deg
y_T	0.2 sec	0.2 deg

Table 2 Definition for Steady States, Continuous Movements, and Reversals

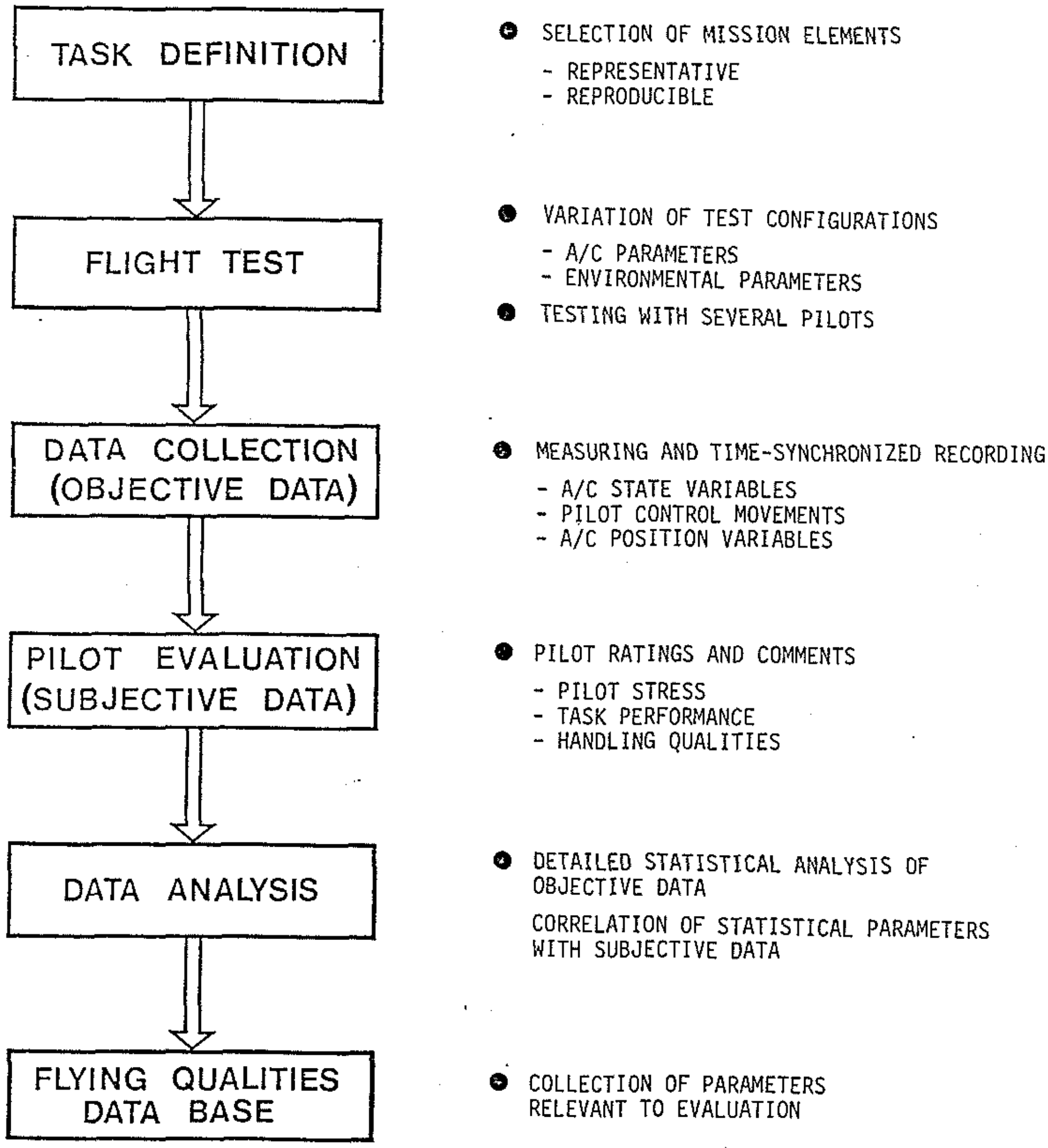

Figure 1 Method

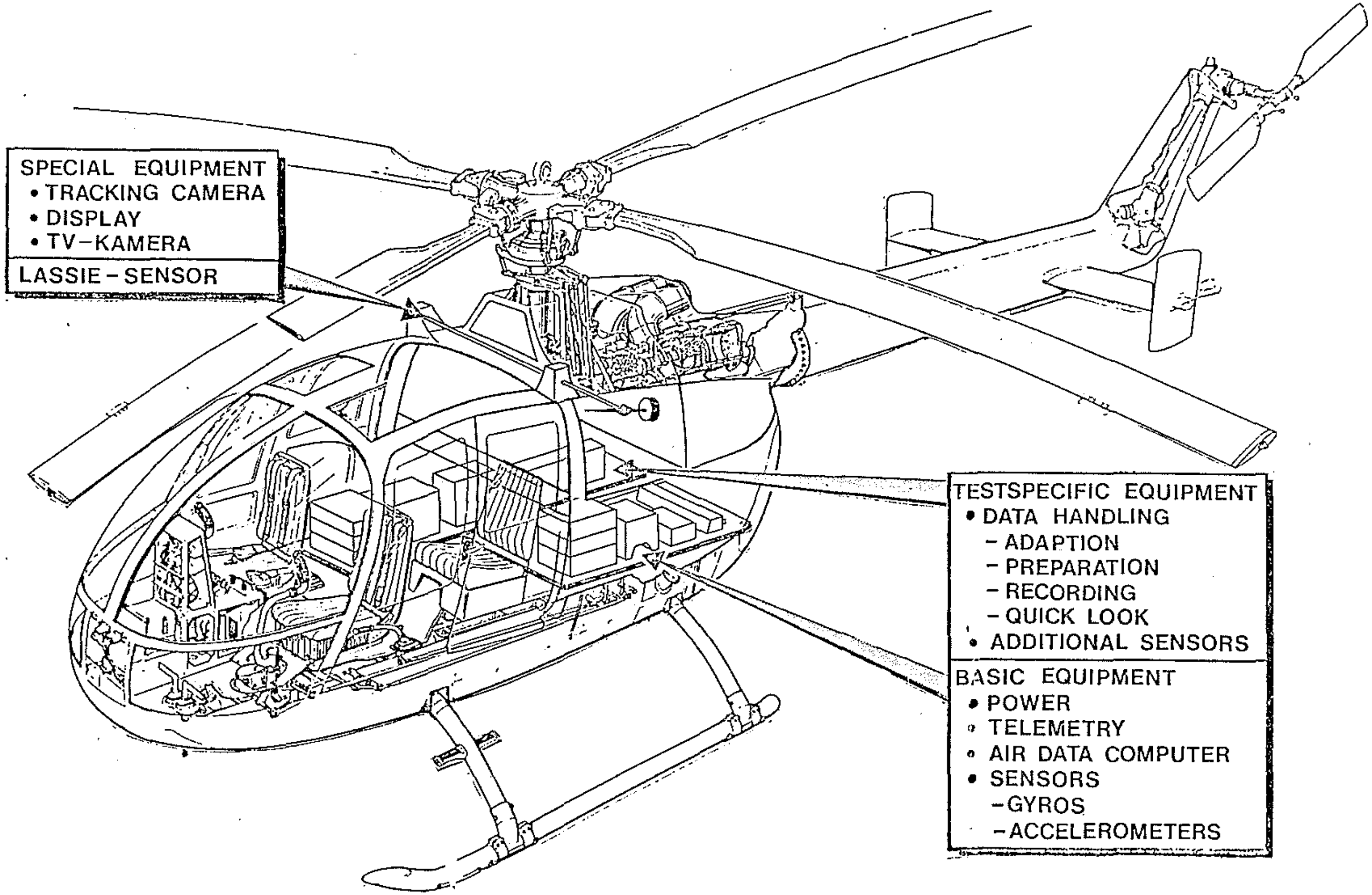

Figure 2 DFVLR Testbed BO 105 S-123

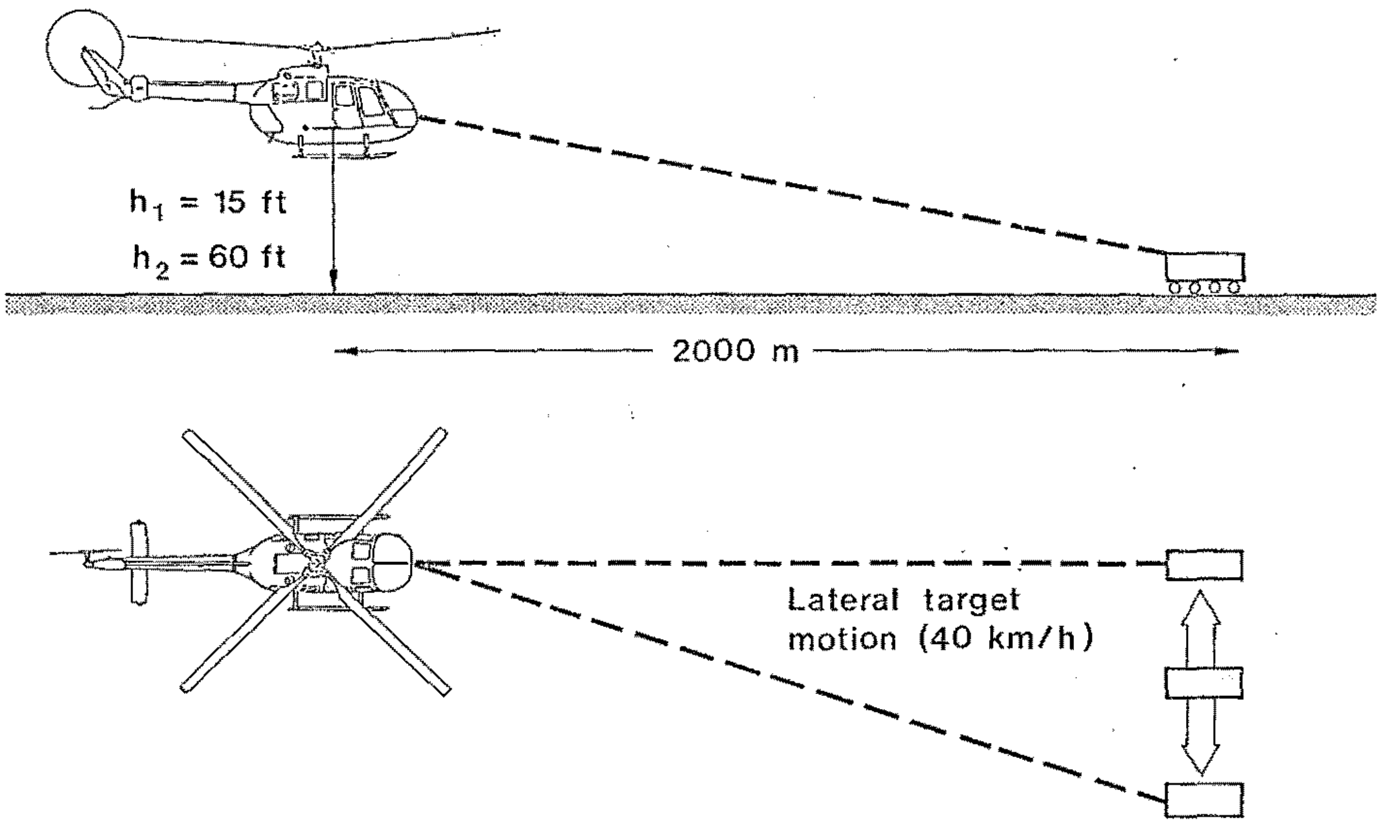

Figure 3 Hovering Tracking Tests

ADEQUACY FOR SELECTED TASK		HELICOPTER CHARACTERISTICS FOR SELECTED TASK	PILOT STRESS IN SELECTED TASK	PERFORMANCE OF THE TASK	PILOT RATING
Satisfactory — Yes		Excellent	No particular	Task performance is optimal	1
		Good	No particular	Good accuracy	2
		Fair	Minimum	Fair accuracy	3
Satisfactory — No	Improvement justified	Minor but annoying deficiencies	Low	Minor inaccuracies	4
		Moderately objectionable deficiencies	Moderate	Fair inaccuracies	5
		Very objectionable but tolerable deficiencies	High	High but tolerable inaccuracies	6
Acceptable (Yes → Satisfactory) — No	Improvement necessary	Significant deficiencies	Very High	Deficiencies in the task performance	7
		Considerable deficiencies	Intensive	Considerable deficiencies in the task performance	8
		Very considerable deficiencies	Maximum	Task performance is not warranted	9
Task practicable (Yes → Acceptable) — No	Improvement mandatory	Very considerable deficiencies	Maximum	Task partial not fulfilled	10
Pilot's decisions (→ Task practicable)					

Figure 4 Pilot Rating - Master Page

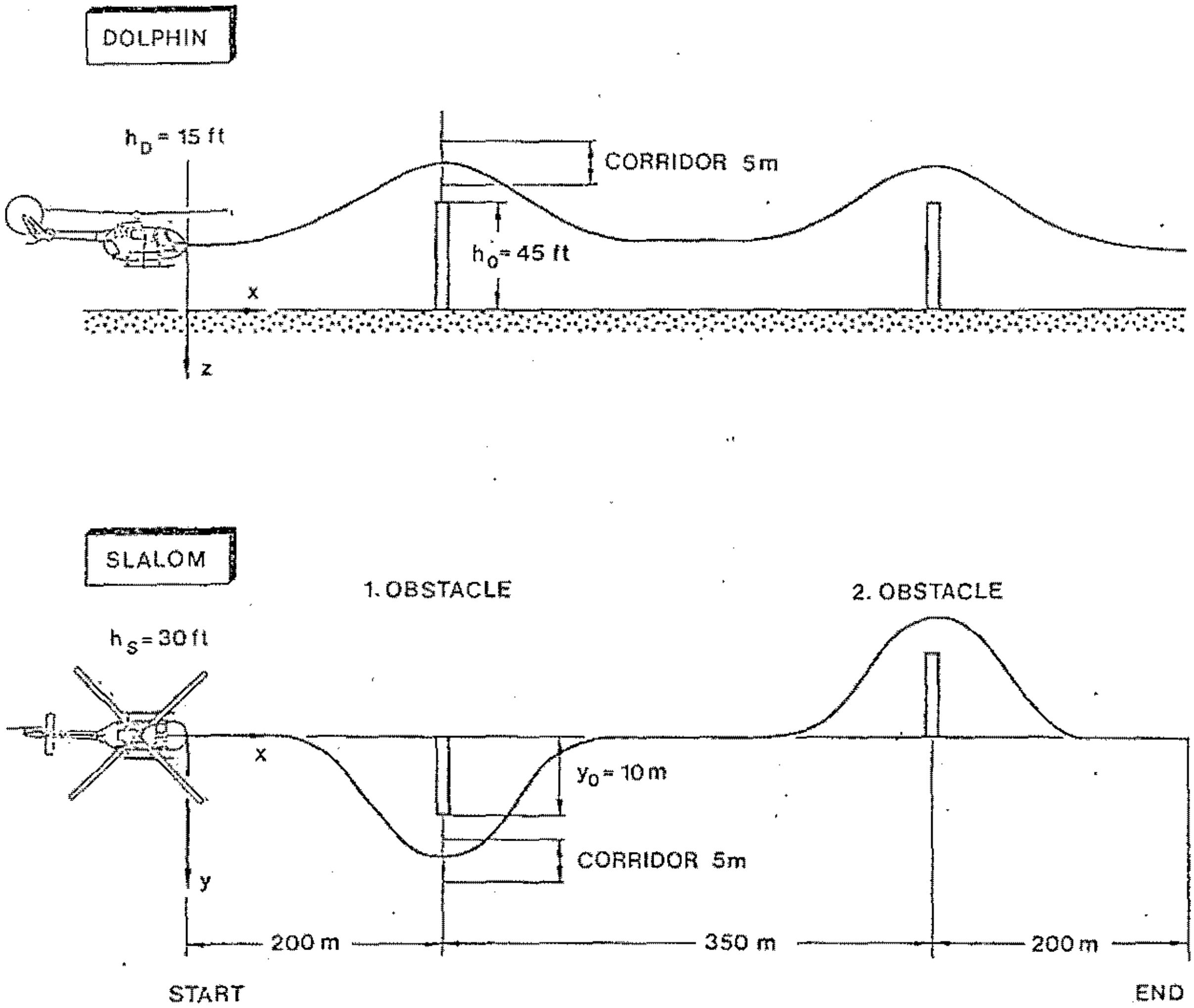

Figure 5 Slalom/Dolphin Tests

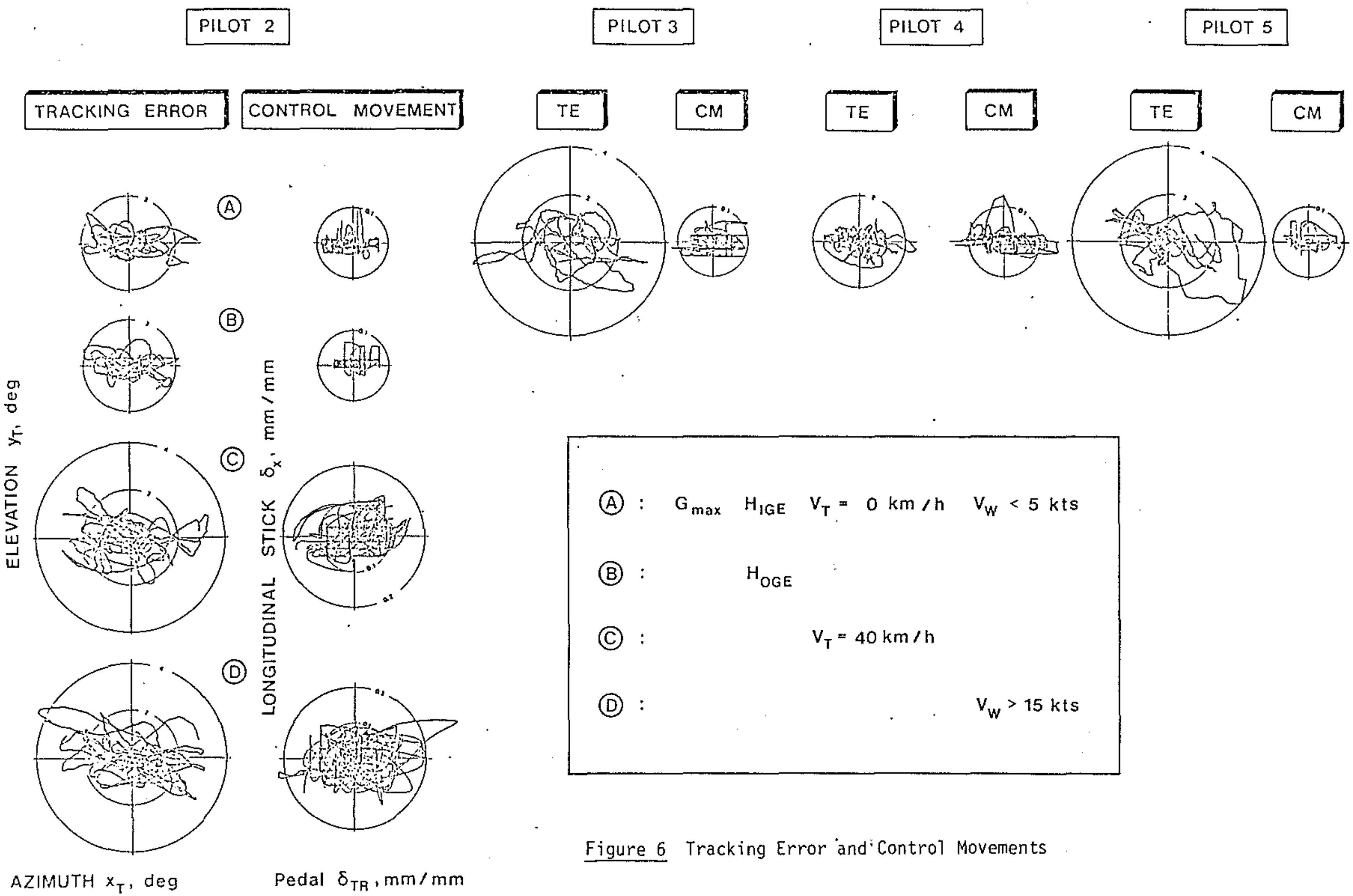

Figure 6 Tracking Error and Control Movements

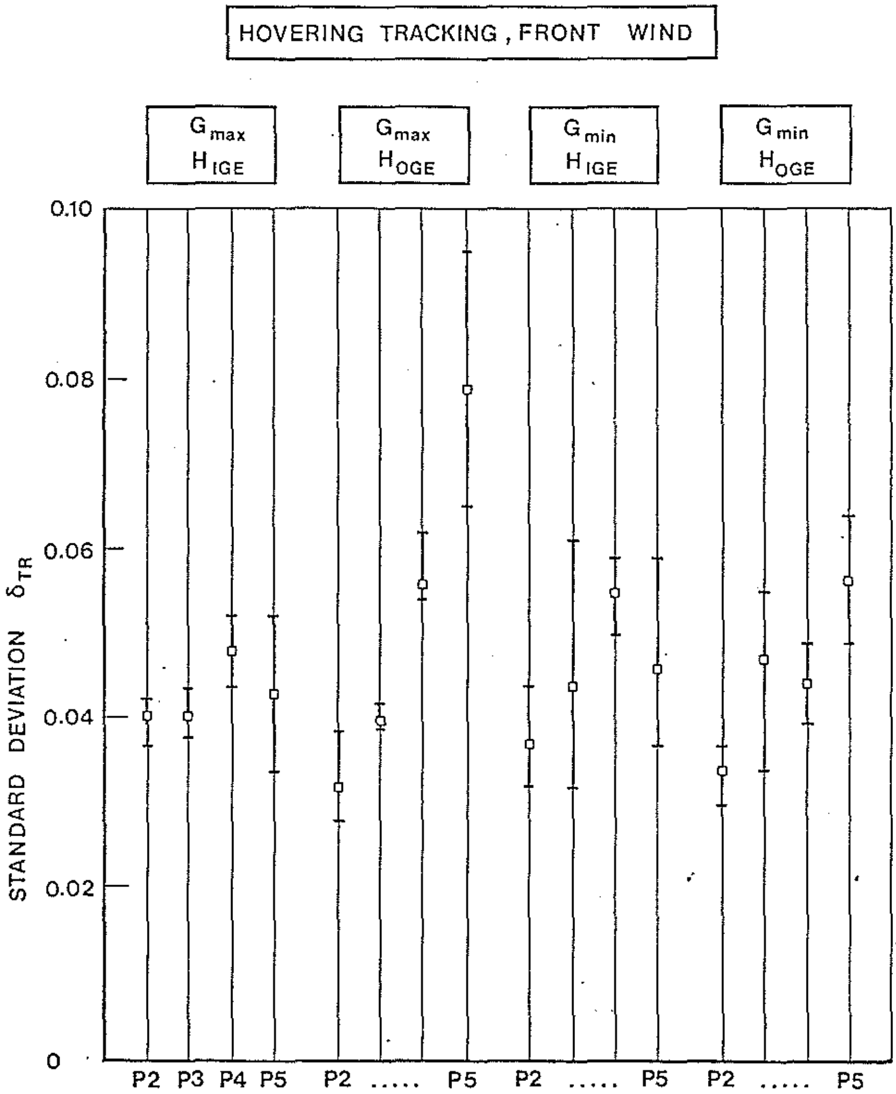

Figure 7 Standard Deviation in Relation to the Pilots and the Test Configurations

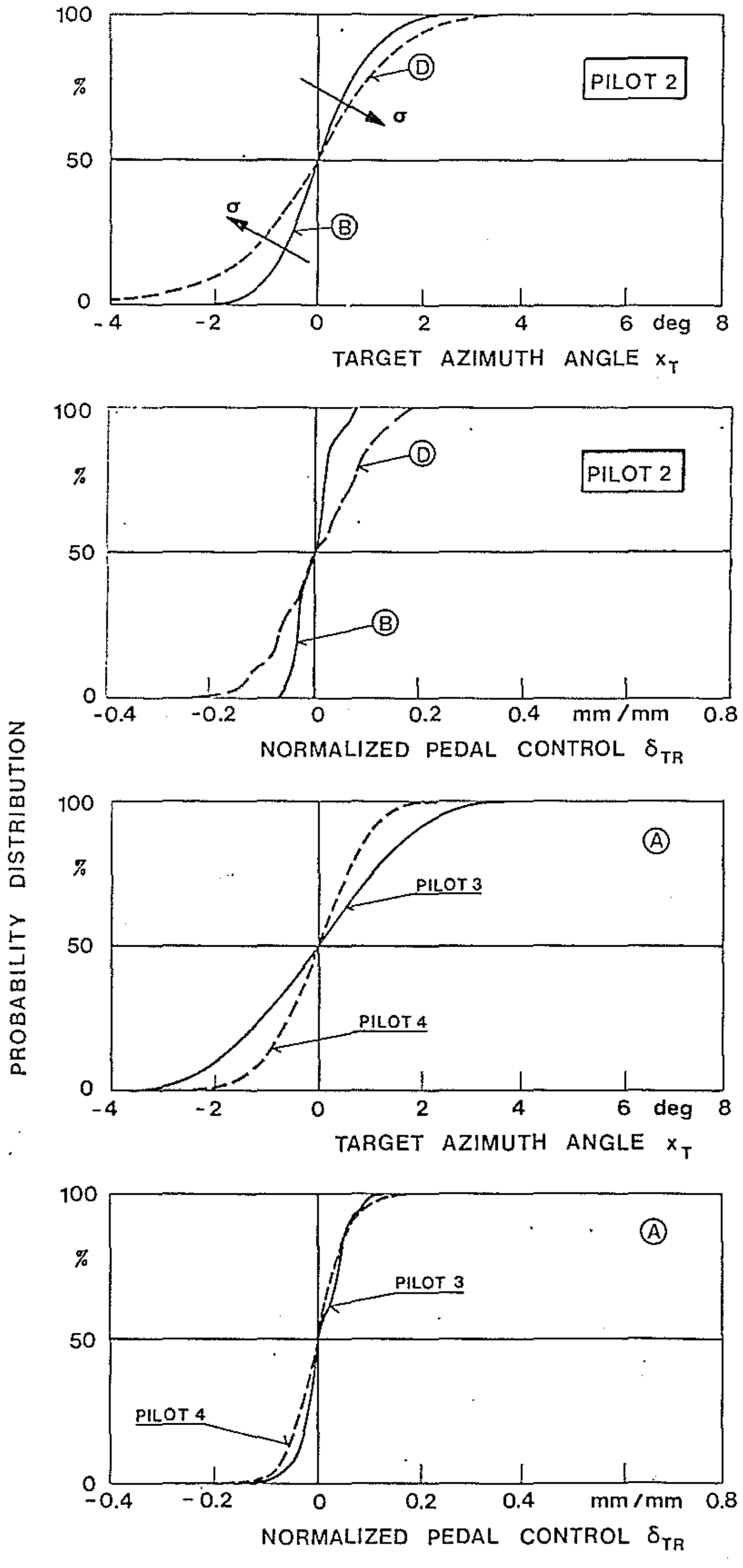

Figure 8 Probability Distribution of the Target Azimuth Angle and the Normalized Pedal Control

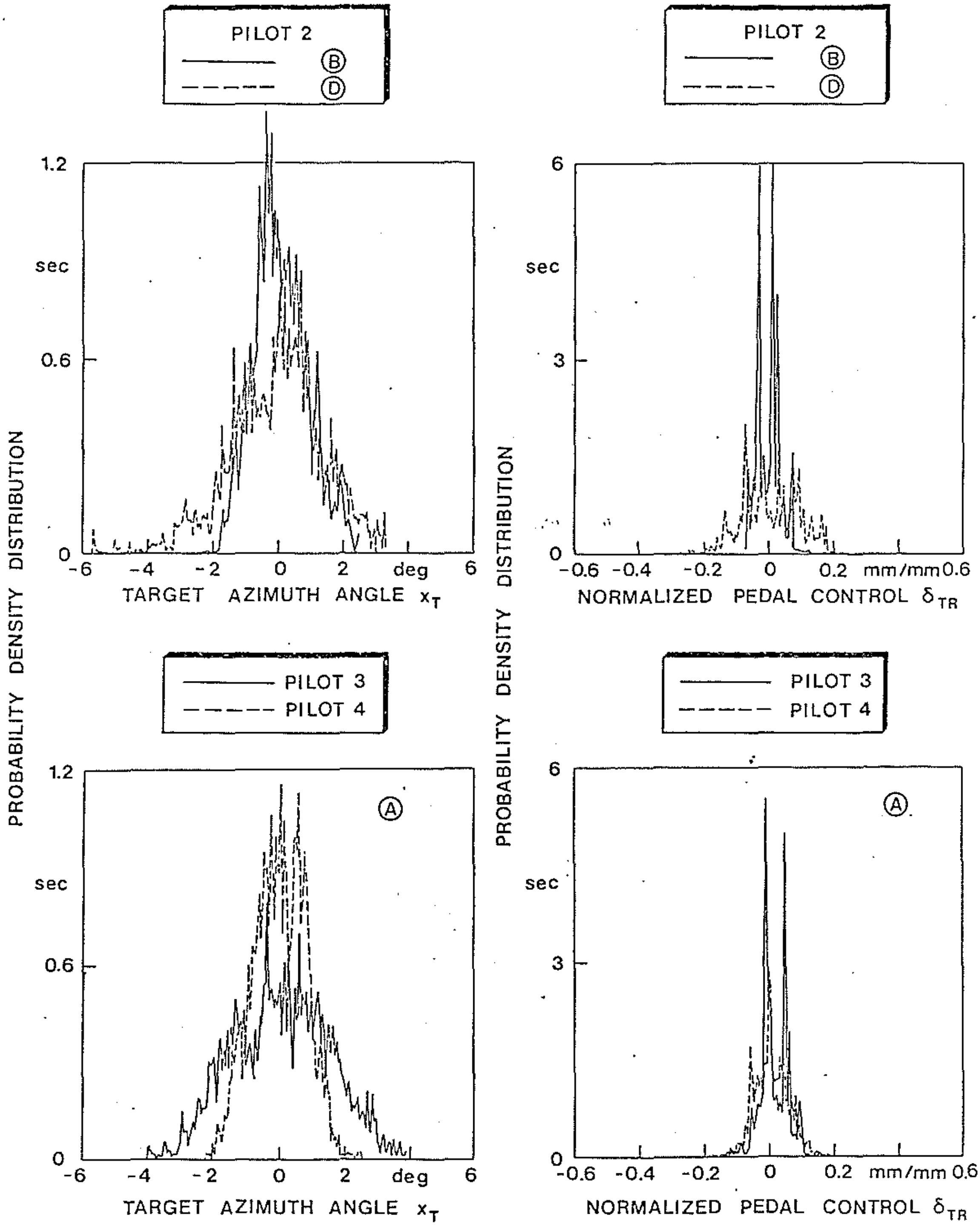

Figure 9 Probability Density Distribution of the Target Azimuth Angle and the Normalized Pedal Control

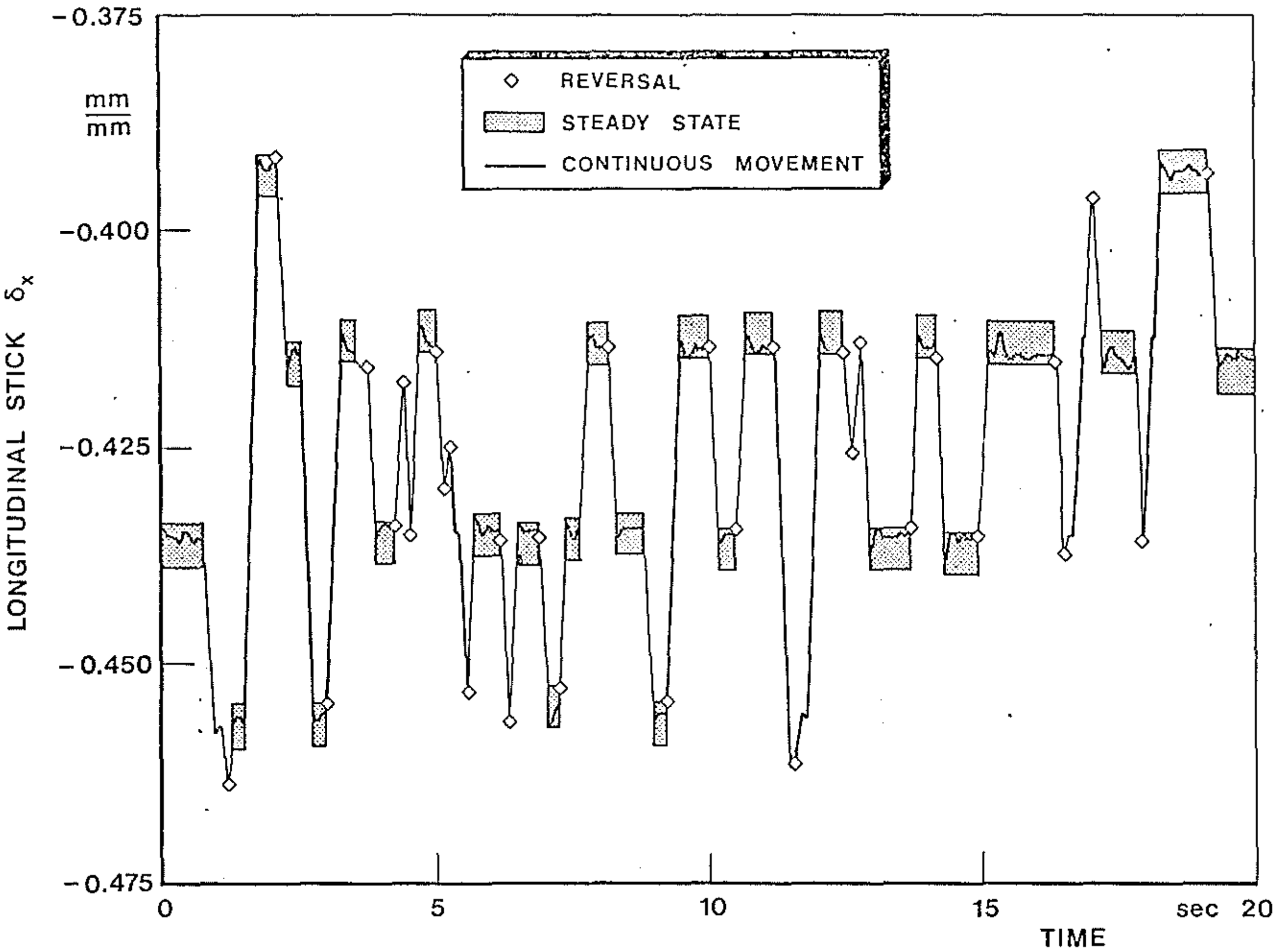

Figure 10 Steady States, Continuous Movement and Reversals Definition

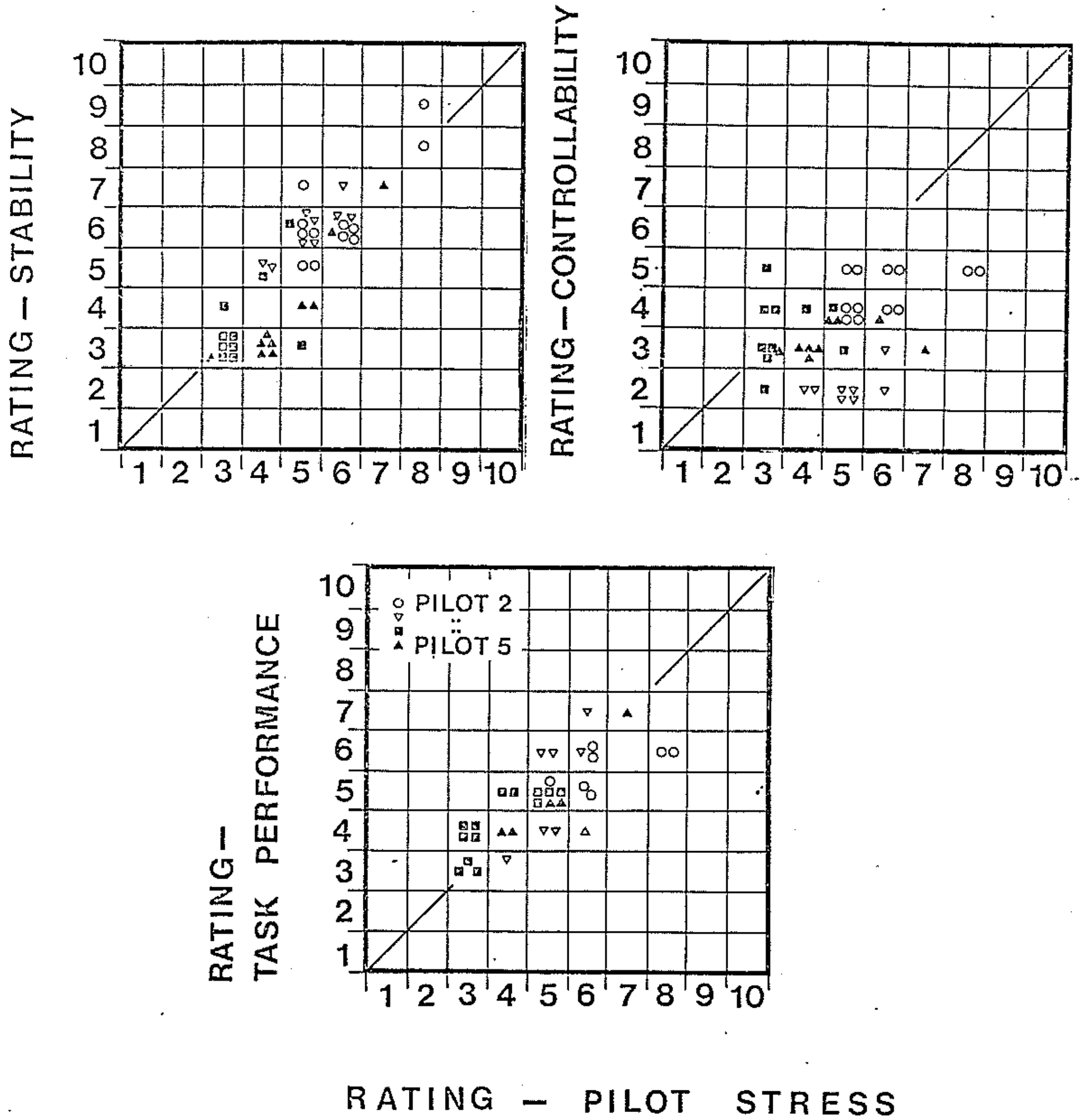

Figure 11 Pilot Ratings

	PR	σ_{δ_x}	σ_{δ_y}	$\sigma_{\delta_{TR}}$	σ_{x_T}	σ_{y_T}	$\left(\frac{TCM}{TSS}\right)_{\delta_x}$	$\left(\frac{TCM}{TSS}\right)_{\delta_y}$	$\left(\frac{TCM}{TSS}\right)_{\delta_{TR}}$	$\left(\frac{TCM}{TSS}\right)_{x_T}$	$\left(\frac{TCM}{TSS}\right)_{y_T}$
PR	1										
σ_{δ_x}	.63	1									
σ_{δ_y}	.65	.64	1								
$\sigma_{\delta_{TR}}$	.84	.66	.68	1							
σ_{x_T}	.76	.70	.55	.76	1						
σ_{y_T}	.58	.73	.66	.63	.66	1					
$\left(\frac{TCM}{TSS}\right)_{\delta_x}$	.81	.75	.74	.86	.77	.68	1				
$\left(\frac{TCM}{TSS}\right)_{\delta_y}$	.50	.48	.58	.56	.40	.39	.69	1			
$\left(\frac{TCM}{TSS}\right)_{\delta_{TR}}$	.57	.44	.49	.78	.52	.53	.58	.58	1		
$\left(\frac{TCM}{TSS}\right)_{x_T}$	.65	.36	.35	.70	.70	.44	.56	.32	.61	1	
$\left(\frac{TCM}{TSS}\right)_{y_T}$	.67	.71	.66	.73	.56	.78	.79	.69	.63	.42	1

Figure 12 Correlation Matrix

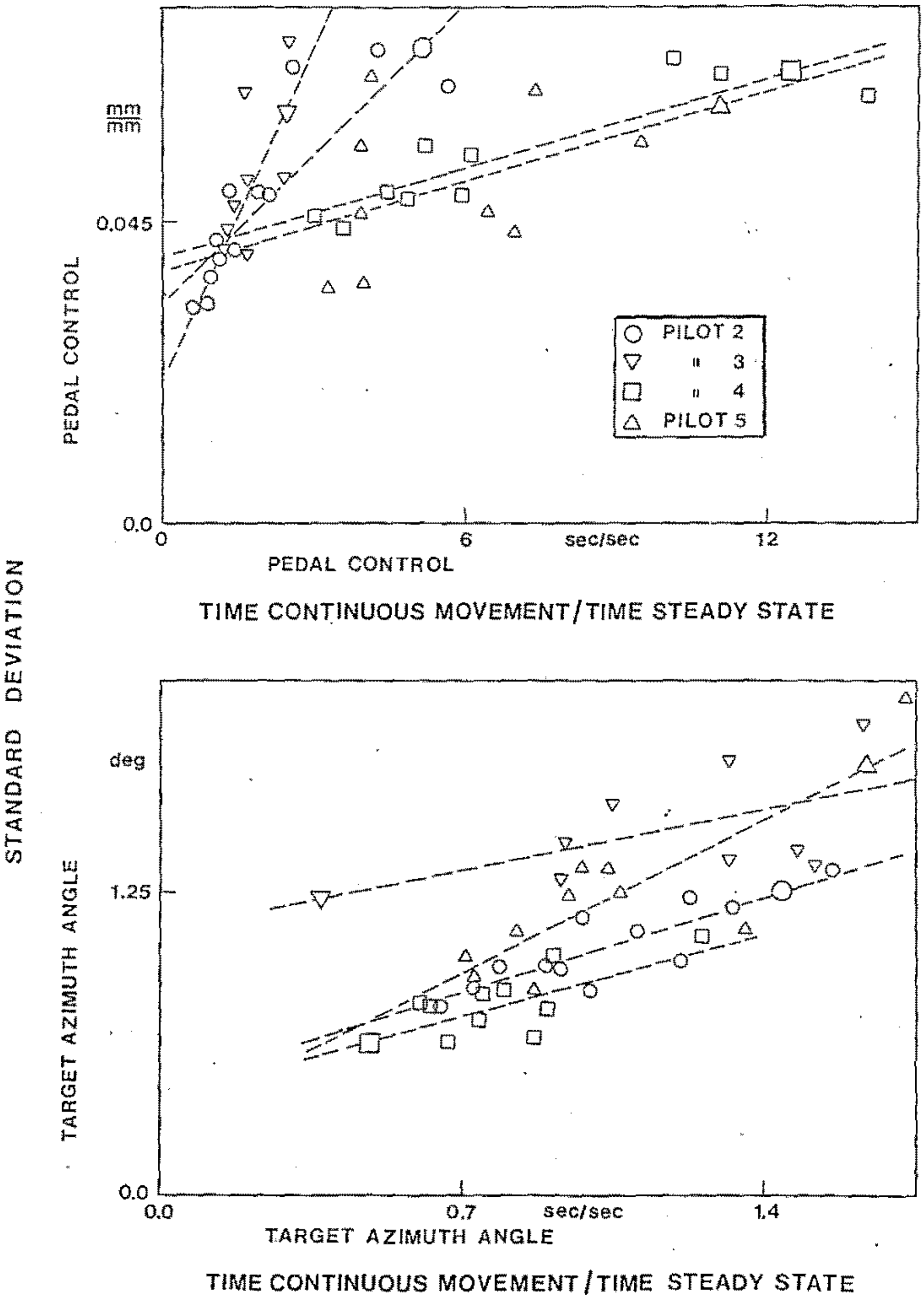

Figure 13 Standard Deviation as a Function of the Dynamical Content

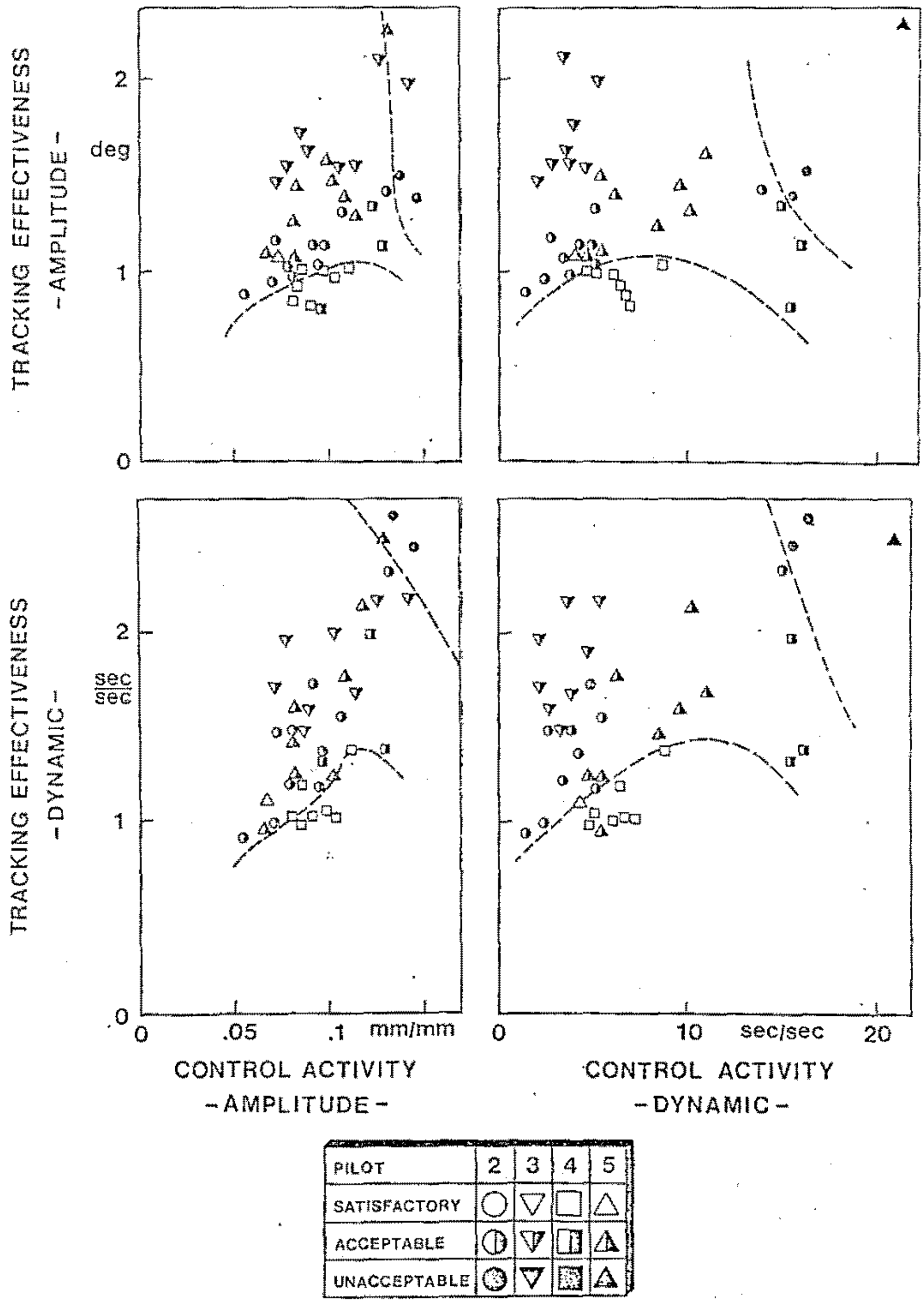

Figure 14 Tracking Effectiveness in Relation to the Control Activity