N94-13302

The Application of Active Side Arm Controllers in Helicopters

R. Knorr, C. Melz, A. Faulkner, M. Obermayer

Eurocopter Deutschland GmbH
Dept. Guidance and Control
P.O. Box 80 11 40
8000 München 80
Germany

ABSTRACT

Eurocopter Deutschland (ECD) started simulation trials to investigate the particular problems of Side Arm Controllers (SAC) applied to helicopters.

Two simulation trials have been performed. In the first trial, the handling characteristics of a "passive" SAC and the basic requirements for the application of an "active" SAC were evaluated in pilot-in-the-loop simulations, performing the tasks in a realistic scenario representing typical phases of a transport mission. The second simulation trial investigated the general control characteristics of the "active" in comparison to the "passive" control principle.

A description of the SACs developed by ECD and the principle of the "passive" and "active" control concept is given, as well as specific ratings for the investigated dynamic and ergonomic parameters affecting SAC characteristics. The experimental arrangements, as well as the trials procedures of both simulation phases, are described and the results achieved are discussed emphasizing the advantages of the "active" as opposed to the "passive" SAC concept. This also includes the presentation of some critical aspects still to be improved and proposals to solve them.

Presented at Piloting Vertical Flight Aircraft: A Conference on Flying Qualities and Human Factors, San Francisco, California, 1993

NOMENCLATURE

AC	Attitude Command
ACAH	Attitude Command/Attitude Hold
ACT	Active Control Technology
CHR	Cooper Harper Rating
ECD	Eurocopter Deutschland GmbH
FCC	Flight Control Computer
FRP	Finger Reference Point
IC	Inceptor
MTE	Mission Task Element
NSRP	Neutral Seat Reference Point
PIO	Pilot Induced Oscillations
RC	Rate Command
RCAH	Rate Command/Attitude Hold
SAC	Side Arm Controller
e_θ	rms tracking error pitch axis
e_ϕ	rms tracking error roll axis
rms	root mean square

INTRODUCTION

With the increase of requirements in both civil and military operations, conventional control technologies using mechanical linkages and automatic flight control systems with limited authority cannot relieve the pilot from higher mental and manual control activity. To alleviate pilot workload, today's high performance fixed wing aircraft as well as some transport aircraft use Active Control Technology (ACT) employing Fly-By-Wire, Fly-By-Light and full authority AFCS.

These technologies also enable the

employment of advanced primary controllers which present the aircraft designer with a great deal of freedom to produce an ergonomically more attractive cockpit. Different types and configurations of Side Arm Controller (SAC) have been investigated in several programs [1, 2, 7]. With the SAC employed in production aircraft new problems have been encountered as in particular Pilot Induced Oscillations (PIO), roll ratched, bio-dynamic interactions, command priority within the cockpit, etc.

Within the definition phase of a future FBW medium transport helicopter, Eurocopter Deutschland (ECD) performed a number of experiments to investigate the particular problems of SAC applied to helicopters. To this end, a 2-axis "active" cyclic and 1-axis "active" collective SAC had to be developed. Active inceptors (ICs) were choosen for the study because they gave the greatest flexibility of investigating different force gradients. But more important, was the aspect to asses the application of "active" SACs. Another main interest lay in the design of SAC devices, which should be able to be integrated into existing helicopters to perform inflight-simulation tests. As this aim excluded the design of an electro-hydraulic position servo system, the position servo system was realised by direct current linear motors.

Since the application of "active" SAC is an advanced concept, extensive simulator evaluations are necessary to optimise their ergonomics and dynamic characteristics together with the Flight Control Systems. To reach this goal, the simulation trials have been divided into three phases.The first phase consisted of pilot-in-the loop ground simulation trials where the SACs have been used as "passive" devices to concentrate on ergonomic aspects when assessing the handling characteristics of the SACs in a realistic scenario. The second phase represents off-line-simulations to investigate the general characteristics of "active" in comparison to "passive" controllers and to evaluate the dynamic characteristics of the "active" SACs with respect to the recommendations made in the first phase. In the third phase the "active" SACs will be tested in flight trials with a wide range of flight tasks from transport mission elements up to aggressive MTEs.

The report gives an overview of the experimental arrangements, the trials procedures and the results of the simulation trials of Phase I and II.

PASSIVE AND ACTIVE INCEPTORS

In the last 15 years several investigations at a number of research institutes have been undertaken dealing with the design of "active" controllers [3, 4, 5, 6]. Since the definition of "active" controllers sometimes vary between the different publications, it seems appropriate to stress the distinction between the "passive" and the "active" control principle (Fig. 1, 2).

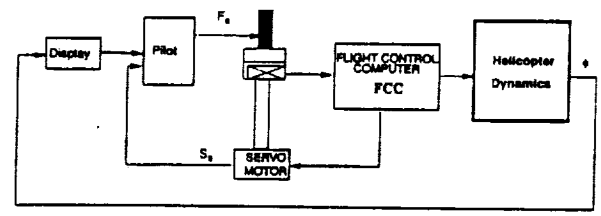

Fig. 1: Control Loop with "passive" Side Arm Controller

In the "passive" SAC the pilot feels spring forces according to the applied stick deflection which is the control input to the Flight Control Computer (FCC). These forces are realised either by a spring and damper package or by a servo controlled position system. In the first case the pilot's controller forces are usually fixed but a servo controlled position system can be used to vary the spring stiffness, damping, breakout forces, zero position easily to a pre-defined force deflection control law. In the second case the pilot "feels" a simulated control force via the sensor package and the position via the servo mechanism. A drawback of this "passive" control concept, as opposed to conventional controllers, is that the pilot looses the contact with the control surfaces of the aircraft. This means that the pilot looses tactile information and can only use peripheral cues (visual and vestibular) to inform him about his actual flight state and the available control power. Disastrous events could be the consequence if the pilot inadvertently tries to exceed the flight envelope.

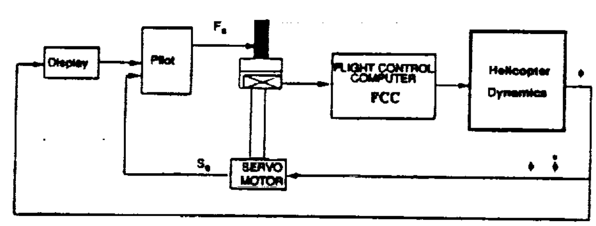

Fig. 2: Control Loop with "active" Side Arm Controller

In contrast to the "active" control concept, the applied stick force is the control input to the FCC and the responding control response (attitude or rate) of the aircraft is fed back as the command input to the position servo system. In this approach, the pilot receives tactile information of the actual flight state of his aircraft on his SAC and with this he retains indications of his actual flight states as well as his control limitations.

The servo controlled SAC ("passive" and "active") of both pilot and copilot gives each crew member a tactical and optical feedback of the command input of the other one. In contrast to the "passive" concept, with the "active" concept there is no more need to nominate a pilot command priority since the commanded grip forces of the two controllers can be summed to obtain one control signal. Fully transparent transfer of command control can be made between the crew and the stick positions synchronised. This important aspect could be demonstrated in phase I.

INCEPTOR PRINCIPLE AND CHARACTERISTICS

As the report aims to stress the general characteristics of an "active" SAC, only the cyclic controller will be considered.

A schematic of the realised cyclic SAC is presented in Fig. 3. It consists of two axis providing a deflection of -18 deg, +12deg in the pitch axis and +/- 14 deg in the roll axis. The SAC has a force sensor at the pilot's hand grip together with a servo-actuator used to position the stick and provide artificial force feel. Since the actuation of the SAC is of secondary importance, it does not have to be included in the flight safety critical path and need hence only be simplex. On the other hand, the force sensing is the primary command input to the FCC and must be quadruplex redundant. In the event of a failure, both pilot and copilot can fly the helicopter without requiring a priority switch. The question of inceptor failure characteristics was one of the objectives of the simulation trials phase I.

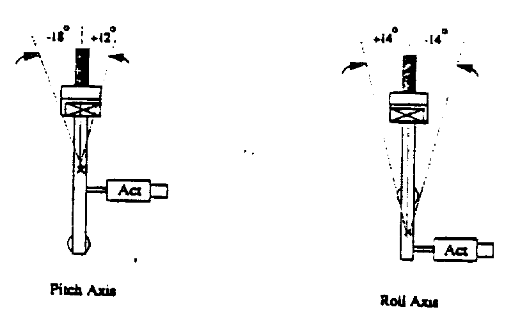

Fig. 3: Schematic of the cyclic Side Arm Controller

The integration of the inceptors in the flight control system with the FCC is shown in the functional block diagram (Fig. 4). The pilot's grip force is measured by an LVDT which is demodulated and sent to the FCC within which scaling, signal conditioning and filtering occurs. Parallel to the grip force, the primary "hands-on" flight state, the pilot is provided with a "beep" trim button on the top of the grip. The "beep" rate is also dependent on the pilots grip force so that if the pilot simultaneously puts a force on the grip and "beeps", the stick will move at a faster speed. An FTR switch is provided to synchronise and zero stick forces if desired. The final output signal of the inceptor position block is used to actuate the stick servo and provide the force feel.

Since the motion of the stick is designed to give the pilot tactile feedback of the helicopter response, the actuation bandwidth specification is dependent on the closed loop bandwidth of the helicopter and flight control system. Analyses of the closed loop bandwidth for the defined helicopter indicated a bandwidth requirement for the actuator of at least 1 Hz for both longitudinal and lateral since the differences in the corner frequency for the axes was only marginal.

SIMULATION TRIALS PHASE I

SIMULATON FACILITY

For pilot-in-the loop simulation trials both ECD and the Military Aircraft Divisions of DASA share a common simulation facility located in the Military Aircraft Division. The main features of the simulation facility at the time of the simulation trials Phase I shows Fig. 5, Fig.6:

- Denelcor HEP (Heterogenous Element processor) Simulation Computer with parallel processor architecture (A), (The HEP simulation computer has meanwhile been replaced by a more powerful HARRIS Nighthawk computer, together with a new interface computer)
- GE Compu-Scene IV computer image generator (B)
- fixed base with provisions for buffeting and g-seat
- 6 channel dome projectionsystem (C)
- Interface computer between cockpit and simulation computer (D)
- Hydraulic buffeting platform with

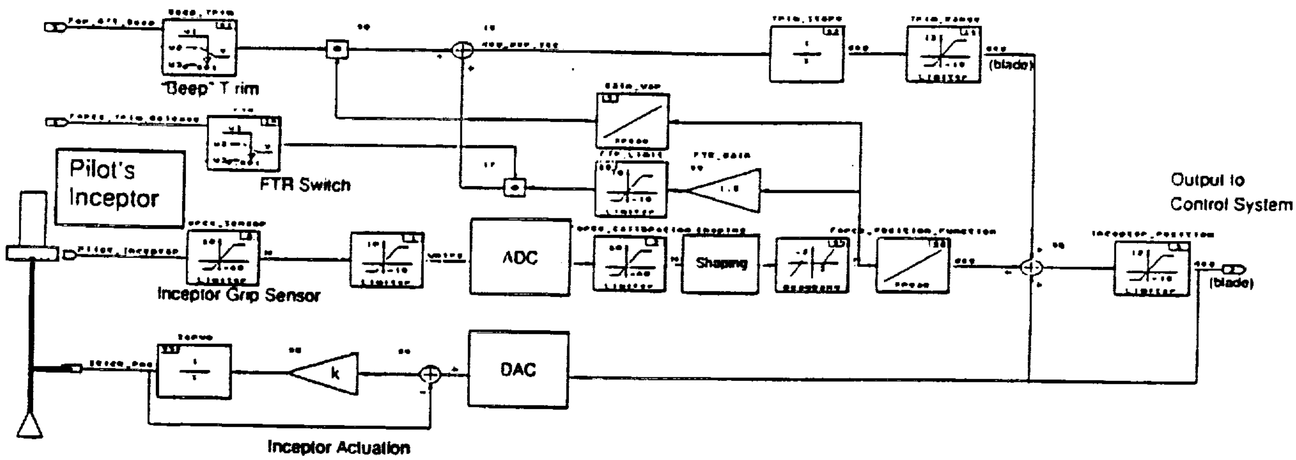

Fig. 4: Passive Inceptor Simulation Set-up

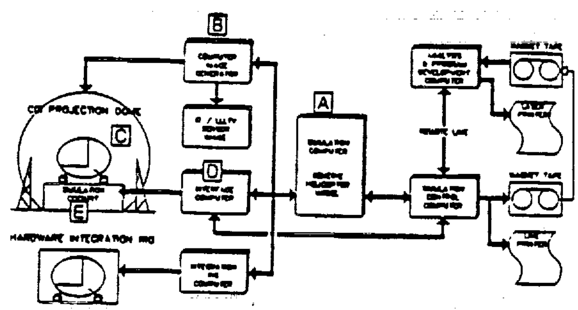

Fig. 5: ECD Helicopter Simulation Facility

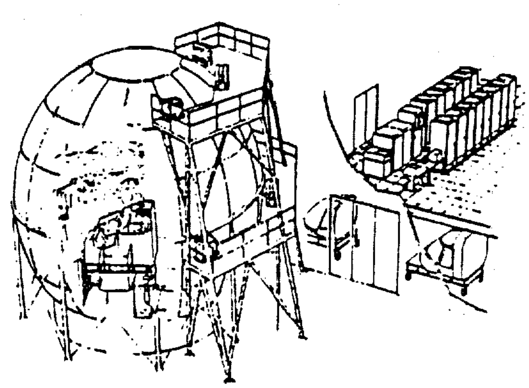

Fig. 6: Compu-Scene IV Dome Projection System

exchangeable cockpits

- large field of view (+/-70 deg horizontal, +70/-40 deg vertical)

ERGONOMIC ASPECTS

The right hand inceptor was installed horizontally with a slight (15°) tilt inward which was found to be a more ergonomic position than a purely vertical grip (Fig. 7, 8). Provision was made to adjust the position of the inceptor relative to the seat. The left hand inceptor was installed sloping downward with adjustment provision in the vertical and horizontal directions (Fig. 9). An overview of the choosen inceptor/seat geometry is given in Fig. 10.

A total number of 15 pilots, plus several other persons, were requested for evaluation of the flight controls and seat ergonomics. As published in [6] measurements as per Fig. 11 were made, which covered a significant range of percentiles. The flight experience of the pilots ranged from several hundred hours (private pilot) to nearly 10000 hours (test pilot) with different combinations of IFR and VFR time (civil/military) and varying levels of simulator experience and aptitude.

Fig. 7: Cockpit View of the Cyclic Controller (side view)

Fig. 8: Cockpit View of the Cyclic Controller (front view)

Fig. 9: Cockpit View of the Cyclic and Collective Controller

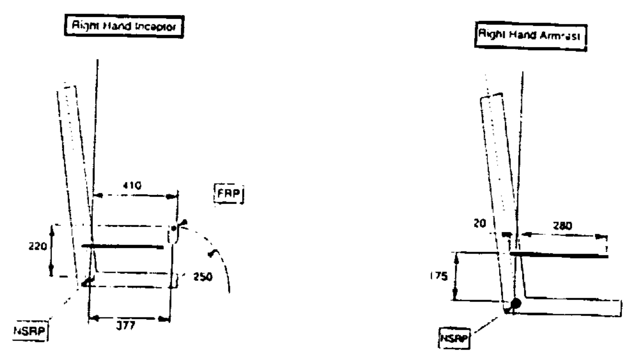

Fig. 10: Inceptor/Seat Geometry, dimensions in [mm]

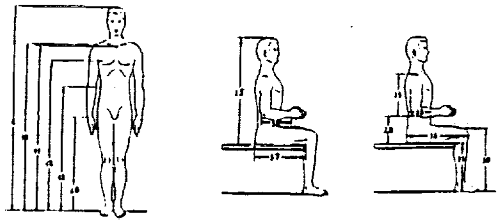

Fig. 11: AGARD-AG-205 Standard Definitions

FLIGHT MECHANICS MODEL

The helicopter flight characteristics are simulated by a non-linear simulation program calculating all external forces and moments of the individual components (e.g. main rotor, tail rotor, fuselage, empenage) based on non-linear aerodynamic coefficients from windtunnel data. The sum of these forces and moments including external influences like wind and ground effects yield the helicopter motion which is presented to the pilot on cockpit instruments and in the computer generated image.

FLIGHT CONTROL SYSTEM CONCEPT

Analysis of the defined helicopter dynamic characteristics showed a classic poorly damped phygoid mode and a better damped roll mode as well as a poorly damped "Dutch Roll" mode. For the simulation trials, a simple stabilisation system was realised with a quasi attitude hold

SIMULATION TASKS

To get as many results as possible concerning the influence of ergonomics and appropriate SAC characteristics under most realistic conditions, it was decided to perform the tasks in a realistic scenario representing typical phases of a tactical transport mission. The task elements were arranged so that they cover the full range of control input types between small/slow (IFR-cruise) and large/fast (VFR-NOE). The pilots were requested to asses their performance and workload for each task element with special emphasis on the SAC characteristics.

ASSESMENT METHOD

The basis for assessment was the Cooper Harper Rating (CHR) scale. Though not easy to differentiate, the pilots were requested to give specific ratings for the parameters like force levels, and gradients in all axes, controls travel and sensitivity, trim speeds, trim release function as well as the position of seat and controls.

PASSIVE SAC CONFIGURATION VARIATION

Experiments were performed prior to the trials, to initially determine the range of force displacement characteristics. These showed that at least 3 gradients were required, an initial steep gradient to provide a smooth breakout characteristic followed by a shallow gradient and finally a steeper gradient (Fig. 12, 13).

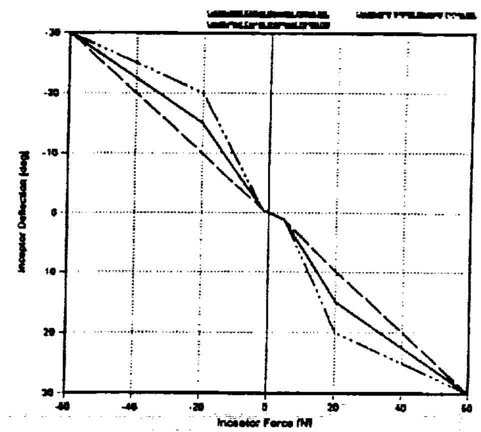

Fig. 12: Longitudinal Cyclic Inceptor Force /Deflection Charact.

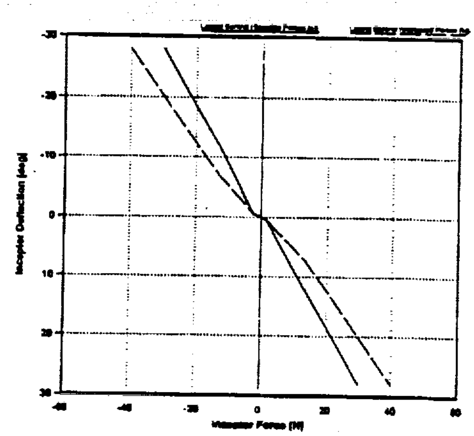

Fig. 13: Lateral Cyclic Inceptor Force /Deflection Charact.

Various combinations were prepared for the simulation trials consisting of:

(a) Basic data set: Cyclic large displacement controller with force gradients

(b) Increased cyclic force gradients

(c) Reduced cyclic force gradients

(d) No cyclic gradients

(e) Controller actuation failure

(f) 50% reduction in inceptor motion

RESULTS

Selected Seat And Control Position

To satisfy all test subjects which covered a wide range of percentiles a seat range of 8 cm in height variation and 18 cm in for/aft position were required. All pilots, however were able to accept the nominal SAC positions without adjustment.

SAC Ergonomics

The shape, position and inclination of the SAC in combination with the armrests were commented very favourably. The stick travels were found adequate. There was, however, a preference by some pilots for reduced forward controller travel. Firstly to prevent the pilot from having to stretch his arm to an uncomfortable position and secondly to minimise the "sliding action" required between the forearm and seat armrest.

There was a good tendency for lower force deflection gradients and in particular for asymmetric left/right gradients to compensate for asymmetric arm muscular characteristics.

SAC functions

The dynamic SAC characteristics were commented by all pilots as being acceptable in the lateral axis but as too "heavy" in longitudinal. The pilots needed too much effort for fast control inputs as in NOE manoeuvres. During high gain manoeuvres, the pilot had to be careful not to "block" the SAC by rigidly hold the grip as this tended to lead to small oscillations. This limitations could be removed later by increasing bandwidth and decreasing the simulator computer delays.

Spot checks confirmed that in the event of a blockage of the SAC actuators flight could be continued, including a safe landing, using beep trim which continues to operate but without stick position changes and pure force control.

RESULTING IMPROVEMENTS FOR PHASE II

Based on the pilot's assessments the following improvements were introduced.

- increase of bandwidth to 4 Hz at 25% control amplitudes
- lower force gradients to the right

SIMULATION TRIALS PHASE II

As the results from the simulation phase I showed mainly the control handling under ergonomic aspects, the prime objective in this phase was to investigate the improvements achievable when employing the "active" control characteristics to the SAC.

The simulation phase II was divided into 2 steps:

In the first step, only engineer-in-the loop simulations were performed, since evaluation of the general characteristics of the "passive"/"active" control characteristics at this stage did not need any pilot involvement.

In the second step, still to be performed, the dynamic characteristics of the cyclic controller will be optimised and fixed through pilot-in-the loop simulations in preparation for the later flight trials

SIMULATON TEST CONFIGURATIONS

Since the first step had not been the objective to evaluate an optimal dynamic characteristic for the "active" SAC, a test facility with a simplified control task was set up to investigate the control handling of the two control concepts in parallel.

The tests were performed in a realistic cockpit mock-up in which the ergonomic aspects like ingress/egress, armrest/seat/SAC configuration could be taken into account.

HELICOPTER MODEL AND SAC DYNAMICS

System dynamics represented a stabilised, decoupled helicopter with pitch and roll dynamics and a selectable RCAH or ACAH response type. This was realised by a simple lag filter (ACAH) or a lag plus additional integral filter (RCAH). For the first approach the time constants for the control modes were, up to for AC: $T_\theta = 2s$, $T_\phi = 1s$, and for RC: $T_q = 1s$, $T_p = 0.5s$, which covers a wide range of light to medium weight class helicopters.

The values for the force deflection characteristics for the investigation of the "passive" characteristics were taken as they were recommended from phase I.

EXPERIMENTS

To evaluate the control handling, a target tracking task in one control axis for, both pitch and roll, was established consisting of a randomly moving target circle, which the operator was required to maintain within the centre of a computer generated image of a simplified ADI. The simplified ADI gave the subject additional information about its actual flight attitude during the task. The simulation test arrangement is shown in Fig. 14.

A number of 5 test person, all engineers, 4 of them with flight experience on different simulators, volunteered for the experiment. The trial consisted of a set of 4 different combinations for the tracking task in each axis and per subject with two runs recorded and analysed. Before the test runs were recorded each subject was given unlimited time until he felt familiar with the task, as well as one test run. Two runs were recorded where each run lasted 60s. To determine the tracking performance of each subject the rms value for the tracking error in the pitch axis $e_\theta = (\theta\_target - \theta\_heli)$ was calculated (in the pitch axis as well as in the roll axis).

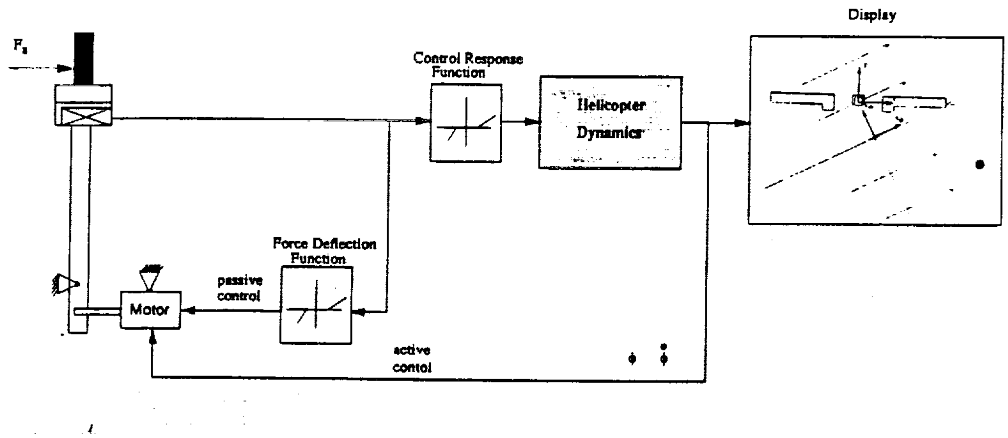

Fig. 14: Simulation Test Arrangement for Simulation Trials Phase II

TEST RESULTS

The rms tracking error e_θ for the different task configurations are presented in Fig. 15, 16. The different values for the rms value of the tracking error in the pitch and roll axis occurred because of different geometric definitions of the pitch and roll attitude for the simplified ADI.

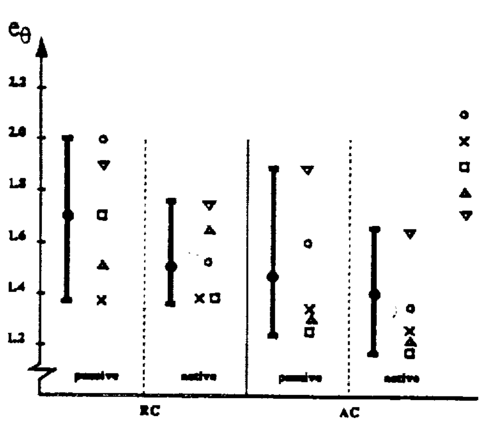

Fig. 15: RMS Tracking Error in the Pitch Axis

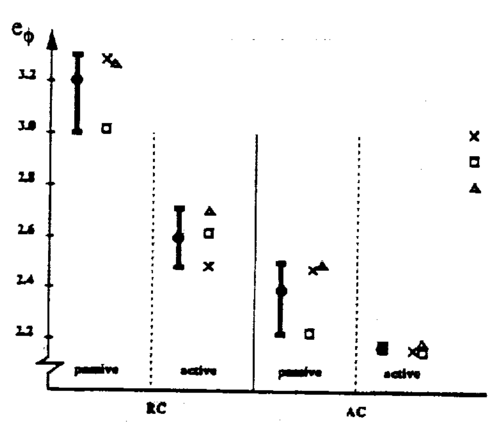

Fig. 16: RMS Tracking Error in the Roll Axis

Passive Mode:

As was expected, in the passive mode, the AC control strategy in both axes showed a lower tracking error as opposed to the RC control strategy. According to the defined control task the pilot is forced to perform precise control inputs to minimize the deviation from the target position. With the AC the pilot directly controls the attitude so he is able to perform attitude changes more precise. With a RC the pilot controls the rate. This provides him a quicker helicopter response but also forces him to integrate the rate to estimate when to counter control to stop the rate. In high aggression manoeuvres with a demand for large but not precise control inputs this control strategy gives him a quick aircraft response. However, in precision manoeuvres, like the target tracking task, this results in higher control activity to achieve a particular attitude and higher deviations from the track.

Active Mode:

Figures 15, 16 show that the rms value for e_θ and e_ϕ for both the RCAH and ACAH control strategy could be reduced with "active" feedback of the rate (RCAH) and attitude for (ACAH) respectively.

In the "active" mode with the RC control strategy, where the actual rate is fed back to the controller, the control behaviour for commanding a rate was totally different. At the moment the pilot applies a force to the hand grip he commands a particular rate which moves the stick in the direction of the applied force. This means that to hold a constant grip force the pilot has to push the stick forwards with the same speed as the stick is controlled by the servo motor. Otherwise the force decreases which consequences in a lower commanded rate. If the grip force is allowed to return to zero the stick stops at a new displaced position and the helicopter at a new attitude. This characteristic can be interpreted as a form of Follow-Up Trim. At the beginning, the subjects criticised the control behaviour of the stick as being too sluggish since the rate feedback did not allow the pilot to perform high frequent control inputs. But, after a short time when he became more familiar with this control characteristic he realised that he needed much less control activity to track the target and found it much more comfortable in comparison to the RC with "passive" characteristic. The improvement tracking error measurements for the "active" configuration confirmed this subjective comment. The advantages of the "active" characteristic were especially noted in the roll axis where the subjects were given a more difficult task with higher control effort as opposed to the pitch axis.

The comparison of the rms value e_θ for the AC control strategy shows once again a further decrease of the tracking error when the "active" mode was employed. This can be attributed to the additional attitude information the pilot receives from the SAC where the position is proportional to the actual attitude of the aircraft and correlated to the visual attitude information on his artificial horizontal display. Together, the subject gains a remarkable lead in his control activities reducing both amplitude and frequency of the control inputs. Furthermore, it is noticeably that in both axes the majority of the subjects achieved nearly identical rms tracking error values for the AC with the "active" feedback. Since all subjects had the same induction phase it would appear that it was more easy to adapt to the "active" controller than the "passive".

CONCLUSIONS

- The SAC concept tested received mostly very positive comments on the ergonomics. A cross-section of pilots were able to use the inceptor without necessitating adjustment relative to the seat. The pilot should be made as comfortable as possible; small points like including the grip inwards give a more natural sitting position.
- A 3-gradient force deflection curve was found adequate for the inceptor in the "passive" mode; asymmetric force/deflection gradients are desirable to compensate for the different bio-mechanical force characteristics of the arm.
- The control ranges of the SAC tested were acceptable, represented the upper limit; where possible a smaller longitudinal range would be desirable to prevent inter-axis coupling in large manoeuvres.
- In both AC and RC control modes the "active" control concept could significantly reduce the tracking error for all subjects.
- The "active" control concept provided the subjects tactile information of their actual flight state helping them to coordinate with the visual attitude information. This was found to make the tracking task easier to learn and to increase subject performance.
- A servo bandwidth of 4Hz as tested was found to be adequate for both "passive" and "active" activation modes.

REFERENCES

1. Landis, K. H.; Glusman, S. I., "Development of ADOCS (Advanced Digital/Optical Control System) Controllers and Control Laws. Vol. 1,2,3, Boeing Vertol Co., Philadelphia.*National Aeronautics and Space Administration, Washington, DC, 1984.

2. Aiken, E.W., "Effects on Side-Stick Controllers on Rotorcraft Handling Qualities for Terrain Flight", NAE Report No: NAS 1.15:86688, A-85141, 1985.

3. Doetsch, K.H.; Röger,W., "The Transfer of Control and Guidance Information to the Pilot through the Manipulator Forces", Sonderforschungsbereich Flugführung, TU Braunschweig, 3300 Braunschweig, P.O. Box 3329, Germany

4. Hosman, R.J.A.W.; van der Vaart, J.C., "Active and Passive Side Stick Controllers: Tracking Task Performance and Pilot Control Behaviour", Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands.

5. Repperger, D, W.*; McCollor D.**; "Active Sticks - A New Dimension in Controller Design", *Air Force Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Ohio,45433, ** Raytheon Service Company

6. "A Review of Anthropometric Data of German Air Force and United States Air Force Flying Personnel, AGARD-AG-205, 1974.

7. Kissel, G.; "Steering Mechanism With An Active Force Feedback, Especially For Aircraft", United States Patent, Assignee: MBB GmbH, Germany, 1979.