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ABSTRACT
This paper presents the results of two flight simulator studies performed at the NLR. The objective of these two simulator studies was to verify two different control concepts for manual flight developed for a future regional aircraft, as well as to find the best Flight Director display for each control option. Results presented in this report indicate that the control system with control augmentation reduce pilot workload. This control system was based in the pitch axis on flight path rate command, flight path angle hold, and in the lateral axis on roll rate command, attitude hold control laws. Further results indicate that a Flight Path Director display based on Flight Path Angle (without drift information) increased pilot rating of pitch situational awareness compared to a conventional cross bar flight director presentation.

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SIMULATOR EVALUATION ON CONTROL AND DISPLAY ISSUES FOR A FUTURE REGIONAL AIRCRAFT

by

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SIMULATOR EVALUATION ON CONTROL AND DISPLAY ISSUES FOR A FUTURE REGIONAL AIRCRAFT

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Abbreviations

ATM	Air Traffic Management
ATS	Auto Throttle System
CMT	Continuous Memory Task
FD	Flight Director
FPA	Flight Path Angle
FPD	Flight Path Director
FPV	Flight Path Vector

Abstract

This paper presents the results of two flight simulator studies performed at the NLR. The objective of these two simulator studies was to verify two different control concepts for manual flight developed for a future regional aircraft, as well as to find the best Flight Director display for each control option. Results presented in this report indicate that the control system with control augmentation reduce pilot workload. This control system was based in the pitch axis on flight path rate command, flight path angle hold, and in the lateral axis on roll rate command, attitude hold control laws. Further results indicate that a Flight Path Director display based on Flight Path Angle (without drift information) increased pilot rating of pitch situational awareness compared to a conventional cross bar flight director presentation.

Background

The flight simulator studies, described in this paper, were part of the "Flight Management Concept Verification" (FMt) program of Fokker[1,2]. Within the FMt program the focus was on cockpit design issues. This program was carried out within the "Aircraft Technology Program" (*Vliegtuig Technologie Programma*, VTP) sponsored by the Netherlands Agency for Aerospace Programs (NIVR). In this program technology was developed for future aircraft.

It is anticipated that future aircraft will have to operate in a busy 4D ATM environment. This ATM environment is likely to increase the workload of pilots. To compensate for this increase an improved cockpit design (including control systems and displays) may be needed.

Within this scope two experiments[3,4,11] were conducted on NLR's moving base Research Flight Simulator. The first experiment was carried out to verify two different manual flight control systems, as well as to find the best (out of three) Flight Director display for each control option. The second experiment focused on an issue raised during the first experiment; this concerned the question whether drift information should be provided in the Flight Director presentation or not.
These experiments were conducted in 1995 in order to prepare for a larger simulator experiment in the first quarter of 1996. This latter experiment involved coupling of the Research Flight Simulator and the NLR ATC Research Simulator. The objective of the overall project was to provide Fokker with the minimum requirements for flight controls, displays and FMS functionality for regional aircraft in a future ATM environment.

In this study the term "**Enhanced Manual**" control is used for a flight control system providing stabilisation and control augmentation in combination with manual input through conventional cockpit controls. The term "**Manual**" control is used for a conventional control system without stability augmentation (except for the yaw damper / turn coordinator).

Study objectives

The objective of the study was to validate or invalidate a number of assumptions or hypotheses. The hypotheses tested during the first experiment were:

1 The workload with an Enhanced Manual control system is lower than with a Manual control system, while equal or better performance is achieved.

2 The situational awareness with an Enhanced Manual control system is higher than with a Manual control system, while equal or better performance is achieved.
3 Workload is decreased by using Flight Director displays based on the Flight Path Vector compared to a conventional crossbar flight director.
4 Situational awareness is increased by using Flight Director displays based on the Flight Path Vector compared to a conventional crossbar flight director, while equal or better performance is achieved.

During the first experiment some concern was raised by pilots on the issue of displaying drift information in the flight path vector presentation on the PFD. The hypotheses tested during the second experiment therefore were:

5 Anticipated advantages in subjective awareness, by displaying the drift information, are outweighed by the disadvantages of presenting a not centred flight director presentation.
6 Accuracy is not adversely affected by removing the drift information from the display.

Aircraft Model

A preliminary aircraft design, called P370-II of a short to medium range fast turboprop aircraft was the basis for the aircraft studied. This 80 passenger seater, has a maximum cruise speed of Mach 0.72 / 300 CAS and has a MTOW of 30.000 kg. The aerodynamic model for this aircraft, which covered the complete flight envelope, was derived using handbook methods. This aero model together with a powerplant model based on a propfan, were employed in the tests. The NLR Research Flight Simulator with a four degree-of-freedom motion system and a two-man glass cockpit was used to conduct this investigation.

Flight Control System concepts description

For the purpose of these experiments a realistic implementation of Manual, Enhanced Manual and Automatic control has been achieved. Hardware implementation issues, such as system architecture, were not part of the FMt program, these issues were addressed in a separate program.

Conventional Manual Control

Being the baseline concept, the Manual flight control concept provides the control architecture found in most contemporary aircraft by means of conventional controls. Part of the workload is reduced by a yaw damper system with turn-coordinator and an Auto Throttle System (ATS). The Manual flight control concept consists of the following:

- conventional pitch, roll and yaw control: elevator control with the control column, aileron control with the control wheel and rudder control with the rudder pedals. The relation between pilot input deflection and control surface deflection was linear,

- turn coordination and dutch-roll damping is provided by the permanently engaged yaw damper/turn-coordinator,

- speed holding and envelope protection with an ATS. This system was engaged during most of the experiments,

- elevator trim by pilot operated switches on the control wheel or by turning the trim wheel directly.

Realistic control forces were simulated. Handling qualities have been verified using the Fokker standard of flight handling requirements. A Fokker test pilot evaluated the flight handling qualities of the P370-II aircraft as implemented in the simulation and qualified the flight handling qualities to meet the Fokker requirements[5].

Enhanced Manual Control System

The objective of the Enhanced Manual flight control concept is to provide improved handling qualities with respect to the conventional means of control. In a previous study by Fokker[6] three different FBW control concepts were studied:

- a Rate Command System
- a Flight Path Vector Command System
- a C^* Command System

From the results of this Fokker study it was concluded that the Flight Path Vector control concept proved to reduce workload the most. The Enhanced Manual Control system used for this experiment, therefore, was based on this system. The handling qualities improvement is achieved by automatic stabilization about all axes, as well as relieving the pilot of trimming the stabilizer after changing the aircraft configuration or speed.

The Enhanced Manual flight control concept consists of:

- flight path, roll and yaw control using pilot inputs through conventional input devices. The pilot controls flight path angle through the control column, roll angle via the control wheel and yaw by means of the rudder pedals,

- a flight control system providing automatic stabilization in all axes. The aircraft maintains commanded inertial flight path angle and bank angle within the limits of the flight envelope after control release,

- an automatic stabilizer trim system,

- a yaw damper / turn coordinator system which is permanently engaged,

- an ATS for speed holding, which was engaged during most of the test runs.

Although the pilot controls the airplane in a different manner, the flight control system has been simulated in such a way that input force per g and displacement resemble those of the Manual control mode while manoeuvring.

Figure 1 shows a block diagram of the control system. The pilot input signal in the control system is derived from the displacement of the control column. The force feel system provides increased force gradients with airspeed through the q-feel system. As in any typical implementation of flight control systems, the pilot input signal passes some signal conditioning, ie deadzone, low pass filtering, limiting and multiplication. The result is considered as a flight path rate command. Within the normal operating flight envelope the control system maintains the commanded inertial flight path angle and bank angle after the pilot releases the controls.

Steering commands are augmented with feedforward lanes to provide the pilot with "crisp" pitch handling by direct elevator control. The feedforward provides faster elevator command in anticipation of the elevator command generated through outer loop gamma error building up. This was applied using the guidelines provided by Gibson[7]. The feedforward commands have been designed such that pitch attitude response following a control input is now K/s like (pure integrator response). This provides a controller without pitch attitude dropback or overshoot after control release, which gives a very predictable response to the pilot and requires little pilot compensation.

An aircraft with Flight Path Angle stabilisation without ATS is unstable in speed when flying slower than that corresponding to the maximum $^{Cl}/_{Cd}$ speed (which is normal during the approach and landing phase). The use of an ATS therefore is necessary for optimal operation of this control system.

Without pilot input, the combination of flight control system and auto throttle system provides flight envelope protection. However, in the present implementation, the pilot is still able to exceed the limits of this envelope by overriding through direct control.

Flight Director System

Previous studies[6] showed that a Flight Director system is essential for decreasing workload and improving accuracy, therefore a Flight Director was included for all control and display options studied.

The lateral FD command for all control display commands were similar. Display type 1, 2 and 4 show this command as a lateral displacement whereas type 3 shows the command as an angle.

In the pitch axis the FD command in combination with the Manual control system includes damping signals usually found in contemporary FD systems. The FPV symbol in display #2, 3 & 4 is positioned on the actual FPA.

In combination with the Enhanced Manual controller the FD command is the difference between the required FPA (as calculated by the FD system) and the commanded FPA (from the control system). The FPV symbol is positioned on the commanded FPV instead of the actual FPV, this is done in order to compensate for the lag between pitch attitude and flight path angle response.

Display description

In most conventional civil aircraft, the flight director steering commands are displayed by "cross bars" relative to the aircraft symbol (boresight) in the middle of the Primary Flight Display. The pilot has to control the aircraft, and thereby also the FD needles, in such a way that the crossbars are centred on the boresight square. This is called "compensatory" tracking. A characteristic of compensatory behaviour is lack of information regarding the source of tracking errors which could compromise situational awareness[12]. An alternative way of presenting steering commands is to display the FPV (where the aircraft is going) which has to be controlled by the pilot in the direction of the desired FPV (the so-called Flight Path Director, FPD). This results in a "pursuit" display. The new displays were of the pursuit type and aimed at increasing situational awareness, without a significant increase in workload. These new displays were compared to the conventional compensatory flight director display.

Instead of the attitude of the aircraft, the new pursuit displays therefore are based on flight path . The Flight Path Director presents steering commands relative to the present FPV to arrive at the desired path. Both FPV and FPD are projected relative to the artificial horizon. Therefore the actual angle of climb or descend (FPV) and the desired climb or descend (FPD) can be read directly from the display. It is this additional information that is expected to increase awareness in the vertical plane.

The commands in pitch and roll can be represented in several ways. Differences in frame of reference (earth- or aircraft referenced), rotating or non-rotating symbols, symbol size and colour were all considered in an iterative design process. The number of display alternatives for the first experiment was reduced by a preliminary evaluation with test pilots. Two pursuit Flight Path Director displays (display #2 & 3) were selected for the first experiment. For the second experiment a variant of display #2 was considered (display #4).

Display #1: Conventional Cross bars Flight Director

In the conventional cross bars flight director (figure 2) a deviation from the desired vertical path is presented by a horizontal bar moving in the direction that a pitch steering input is required (e.g. 'bar moves up' means 'pull up', the so-called "follow the needle"-principle). Any deviation from the desired roll angle, as calculated by the control system, is presented by a vertical bar moving side ways ('a move to the right' means 'turn to the right by banking the aircraft'). The deviations are all referenced to the centre of the screen (boresight square).

Display #2: Cross Flight Path Director with drift information

For both pursuit displays a standard FPV symbol was chosen; a circle with wings and a tail. A cross was chosen as the FPD symbol because humans tend to associate a cross with a target (Fig. 3). Therefore it is unlikely that the FPV and FPD symbols will be confused. The cross FPD indicates a deviation from the desired path by a movement perpendicular to the horizon line in the direction in which a pitch steering input is required (e.g. 'cross moves up' means 'pull up'). Any deviation from the roll calculated by the FD is presented by a lateral movement of the cross sideways in a direction parallel to the horizon line ('move to the right' means 'turn to the right by banking the aircraft'). The deviations are all presented with respect to the Flight Path Vector symbol. Despite the fact that the cross moves in the pitch and roll direction relative to the earth's axis, during the prototyping stage, pilots preferred a cross symbol which did not rotate with the earth's axis. The FPV laterally is displaced from the centre of the pitch ladder by the drift angle. It was initially anticipated that this would increase the situational awareness of the pilot.

Display #3: Ghost Aircraft Flight Path Director (rotating symbol)

A rotating ghost aircraft showing the desired flight path was expected to be the most intuitive display (Fig. 4), because flight track deviation is presented as required roll angle instead of an indication of lateral displacement. The hypothesis is that the awareness in roll will be increased as a result. A symbol similar to the one used in the Airbus 320 was selected. To improve the detection of small roll errors a 'tail' was added to the original Airbus concept. A deviation from the desired vertical path is presented by a movement of the FPD in the aircraft frame of reference. The FPD symbol moves in a direction that a pitch steering input is required (e.g. 'FPD moves up' means 'pull up'). A deviation from the roll angle commanded by the control system is presented by a rotation of the ghost aircraft symbol ('clockwise rotation' means 'turn to the right by banking the aircraft'). The pilot's steering task is to follow the ghost aircraft, based on the "follow the leader principle". Note that the deviations are all presented with respect to the Flight Path Vector.

Display #4: Cross Flight Path Director without drift information

Display #4 was identical to display #2 except that the drift component was removed from the FPV presentation (Fig. 5). The FPD remained positioned relative to the displayed FPV.

Experiment description

All subjects were briefed on the usage of the displays and controls. A training session was conducted to familiarise the subjects with the controls, displays, aircraft dynamics and the scenario's. During all experiments an NLR research engineer acted as pilot not flying in the right-hand seat.

First experiment

Two control systems combined with the original three displays (#1, #2 & #3) resulted in six test conditions. The FD system was used during all tests. For each of these six conditions the subject pilots flew 10 different short tasks (Table 1).

Table 1

task	Speed [kt]	Height [ft]	Heading [deg]
start	170	2000	360
1	170	**climb to 3000**	360
2	170	**descent to 2000**	360
3	170	2000	**turn right to 100**
4	170	2000	**turn left to 090**
5	**accelerate to 250**	2000	090
6	250	**climb to 3000**	090
7	250	**descent to 2000**	090
8	250	2000	**turn left to 350**
9	250	2000	**turn right to 360**
10	**decelerate to 130** configuration changes required	2000	360

After this flight a decelerating curved approach was flown. The curved approach was the SIDES approach to SPL 06 (Fig. 6). This experimental approach was investigated during a previous research project on advanced procedures using MLS guidance[8]. The FD system provides closed loop guidance during the entire approach including turns.

The flight procedure for the approach is detailed in the table below.

Table 2

1	on track reduce to 170 Kt, flaps 7, maintain 2500 ft
2	after flap extension reduce to 160 Kt, maintain 2500 ft
3	at 1 dot below glideslope, gear down
4	on glideslope reduce to 150 Kt, flaps 15
5	Beginning of 2nd turn, reduce to 140 Kt, flaps 24
6	on final, reduce to 130 Kt, flaps 35

During the check-out of this experiment three test pilots participated, whereas five regular airline pilots (average age 29, ±3400 hrs) took part in the data collecting exercise.

Second experiment

Display type number 2 was further scrutinized in this experiment. This display was tested with and without drift information, resulting in display #2 and #4 for the Manual as well as the Enhanced Manual Control System. During the previous experiment the decelerating curved MLS approach was found to be a good test scenario for highlighting problems. Therefore for this experiment this scenario was used. A total of five pilots took part as pilot flying in the left-hand seat; two test pilots, two line pilots and one general aviation pilot.

Qualitative Results

The qualitative data consisted of both post-run questionnaires and written pilot comments.

During the post run questions the pilots were required to rate, on the basis of their own perception, the task just performed. They were requested to compare this with the baseline, which was Manual Control with conventional crossbar configuration. In the first configuration, which was Manual Control with conventional crossbar, the pilots were requested to give ratings in comparison to the aircraft they used to fly. This gives an indication of

Table 3

Task	Description
altitude	Four altitude change tasks; both up and down, low speed and high speed
heading	Four heading change tasks; both large (100 deg.) and small (10 deg.), low speed and high speed
speed	Two speed change tasks; both an acceleration and a deceleration
MLS	One decelerating curved MLS approach (SIDES)

whether the baseline used in this study agrees well to contemporary aircraft. Ratings were allowed in the range from -10 (much worse) to +10 (much better). Results presented are the mean scores of the five airline pilots over 4 groups of tasks (Table 3)

Performance Rating

Figure 7 presents the response to the question how the pilots rated their own performance during the task at hand. From this figure it is evident that the overall trend for all four groups of tasks is very similar. Generally the pilots rated the aircraft they were used to fly only slightly better than the baseline (Manual controls with crossbars). This does agree with the experiment objective of having a baseline aircraft similar to a contemporary aircraft.

When using Manual Control pilots rated their performance higher with display #2 and #3 than with the baseline set-up. Display #2 seems to be preferred over display #3 especially during the curved approach task. In combination with the Enhanced Manual controller pilots rated their performance to be much better than the baseline. The display type used in combination with the Enhanced Manual controller had little effect on the rating.

Pitch Awareness

The rating of the pitch awareness of the baseline aircraft, compared to the aircraft they use to fly, is very neutral (Fig. 8), which again does agree with the objective of having a baseline aircraft similar to contemporary aircraft. For both Manual and Enhanced Manual Control display #2 does increase pitch awareness, whereas display #3 does not. Remarkable is that the Enhanced Manual controller alone, without display alterations, does improve pitch awareness. This effect may be attributed to the observation that with the Enhanced Manual control concept the pilot has more time to scan his instruments as a result of reduced workload.

Roll Awareness

Figure 9 shows that the rating for the baseline aircraft is slightly less, compared to the aircraft the pilots are familiar with. Roll awareness for the Manual control task is somewhat improved by the display #2 and #3 options. Roll awareness is also improved by the Enhanced Manual Controller alone. With the Enhanced Manual Controller the type of display does not effect the roll awareness rating significantly. The expected increase of roll awareness for display #3 (rolling ghost aircraft) did not show up in this experiment.

Workload Rating

Subjective workload ratings were obtained using an absolute rating scale[13]. Results are presented in figure 10. On the absolute scale a high number means high workload. The rating showed that Enhanced Manual resulted in lower workload compared to manual control. In the subjective workload results no display effect could be observed.

Post run questionnaire on second experiment

The results of a comparative rating after the experiment are presented in figure 11 a, b and c. Obviously the majority of the pilots preferred the display without the drift component for both control types tested. Similar results were obtained for military jet Head Up Displays during research conducted in the UK[10]. However, three out of five pilots appreciated some form of drift information on the PFD.

Comments

In the following some pilot comments are presented to illustrate their subjective scores.

First experiment

a The Enhanced Manual control system is very easy to use.
b The Enhanced Manual control system allows an increased scanning frequency of instruments.
c The Flight Path Vector is more appropriate for vertical awareness. Eg. if the FPV symbol is on the horizon I am in level flight.
d The Flight Path Vector display increases scanning and prevents 'tunnel vision'.
e Display #3 (ghost aircraft) is more tiring to the eyes than the Display #2 (cross symbol).
f The rolling ghost symbol FPD (Display #3) is especially difficult in case of small heading changes. Small deviations cannot be observed.

Second experiment

g Advantage of displaying drift information: less attention necessary for NAV display drift indication.
h I did not feel that with/without drift made any difference in accuracy of control.
i Drift is confusing in turns.
j Without drift the display is much more symmetrical, appears smoother.
k Drift is not used during approach, only for decrab/landing in which case you are head-up.

Quantitative Results

The quantitative results are detailed in this section. Results are considered separately for pitch and roll axis.

Pitch Axis

Figure 12 displays the Root Mean Square (RMS) values of the pilot pitch input. This provides an indication of how much the pilot has to steer to accomplish the assigned task. The figure shows that the Enhanced Manual Controller reduces the RMS Values considerably. Differences between displays are very small and generally are not statistically significant. With Manual control an interesting difference between tasks mutually is apparent: tasks which require trimming, such as the speed change and decelerating curved approach, require considerably more control input than those tasks which do not require trimming. For Enhanced Manual Control this difference does not occur since automatic trimming is provided implicitly with this controller.

Figure 13 depicts both vertical- and cross- track deviations for the curved MLS approach path. A reduction in vertical track deviation is apparent when the Enhanced Manual Controller is used, for the display options with crossbars and display #2 this difference is also statistically significant ($P<0.05$). However, no statistically significant difference exists between display options in vertical track deviation.

Roll Axis

Pilot Roll input for the various tasks is displayed in figure 14. A substantial difference exists between Manual and Enhanced Manual control, pilots need less steering input with Enhanced Manual control for most tasks. Again no statistically significant difference appears between displays.

Cross track deviations for the curved approach task are displayed in figure 13. There is a tendency that errors increase with display type (#1,2 & 3), although this was not statistically significant with the available data (at $P=0.05$). Also the difference between Manual and Enhanced Manual control is not always statistically significant, although Manual control appears to give larger cross track deviations.

Double task experiment

A way to measure workload is by measuring the spare mental capacity by means of a secondary task. A secondary task used with success during a previous experiment is the Continuous Memory Task[11] (CMT). During the first experiment two additional curved approaches were flown during which the pilot also had to perform a CMT task. This CMT task consisted of listening to letters presented via the headset, the pilot had to react to two target letters (K & L). If a target letter was detected by the pilot, he then had to press a notice button. If one of the letters was detected three times the subject was required to press the button twice, after which he had to start the count for that target letter from zero.

The pilots were briefed that flying the aircraft was their most important task and that faults were expected to occur in the secondary task. Correctness of response and reaction times were recorded. The two conditions under which the curved approach with the secondary task were executed are:

- Manual Control with crossbar display
- Enhanced Manual Control with crossbar display

One reference trial was conducted where the subject had to perform the CMT only, without flying. Figure 15 displays the percentage of hits and false alarms of the two elements of the CMT the pilots had to perform:

I) Pressing the notice button once when a target letter is detected.
II) Pressing the notice button twice when a target letter is detected for the third time.

The scores on the first task are zero false alarms with an almost 100 % correct score for all three conditions, therefore no differences show up on the first double task. On the second double task, however, a difference does show up; some 15 % less hits occur while flying the curved approach with the Manual Controller when compared to not flying, whereas only about 5% less hits occur when flying the curved approach while using the Enhanced Manual Controller.

Accuracy with and without drift information

Figure 16 and 17 show the vertical and lateral deviations respectively, the mean RMS value as well as the standard deviation are presented. No obvious trend on display influence can be derived from this data; accuracy does not seem to be a function of display of drift information, but much more of controller type. The Enhanced Manual controller does decrease vertical error.

Conclusions

The conclusions drawn from these experiments with respect to the hypotheses are:

Hypothesis #1
The workload with an Enhanced Manual control system is lower than with a Manual control system, while equal or better performance is achieved.

The Enhanced Manual Control system indeed yielded equal or better performance, while subjective as well as objective Pilot Workload measurements reduced.

The Enhanced Manual Control system increases the pilot's own perception of how well he performs. The actual improvement in task accomplishment (deviations from targets), however, was very small if any. Only during the decelerating curved approach, which is a demanding task, small improvements in performance were notable. Therefore the conclusion is drawn that an Enhanced Manual control system will only improve performance under high workload situations.

Hypothesis #2
The situational awareness with an Enhanced Manual control system is higher than with a Manual control system, while equal or better performance is achieved.

Subjective ratings of pitch as well as roll situational awareness indeed increased with the Enhanced Manual control system.

Hypothesis #3
Workload is decreased by using Flight Director displays based on the Flight Path Vector compared to a conventional crossbar flight director.

No significant effect of display type on workload was measured during this experiment.

Hypothesis #4
Situational awareness is increased by using Flight Director displays based on the Flight Path Vector compared to a conventional crossbar flight director, while equal or better performance is achieved.

The Flight Path Director display based on Flight Path Angle (Display #2) indeed increased pitch situational awareness while providing equal accuracy. The display with the rolling ghost type flight director did not increase pitch situational awareness.
Roll awareness does not seem to be affected by display type. The anticipated increase in roll awareness for display #3 (rolling ghost aircraft) did not show up in this experiment.

Hypothesis #5
Anticipated advantages in subjective awareness, by displaying the drift information, are outweighed by disadvantages of presenting a not centred flight director presentation.

Indeed pilots prefer the Flight Director display without drift information above one which does provide drift information.

Hypothesis #6
Accuracy is not adversely affected by removing the drift information from the display.

Data showed that indeed steering input and deviations from track are very similar with or without drift information.

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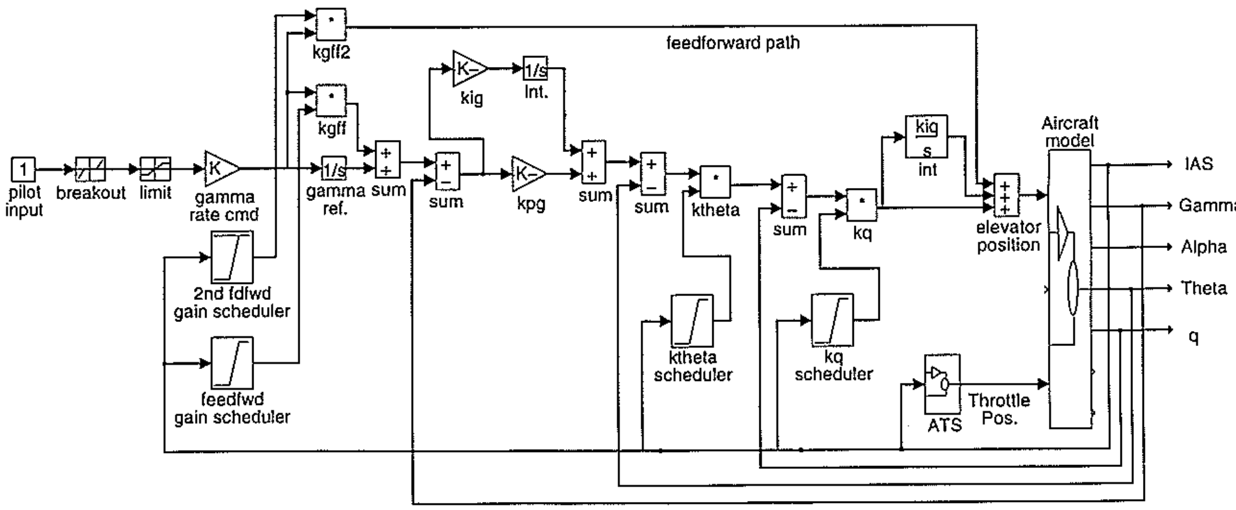


Fig. 1 Block diagram of Enhanced manual control system, pitch axis.

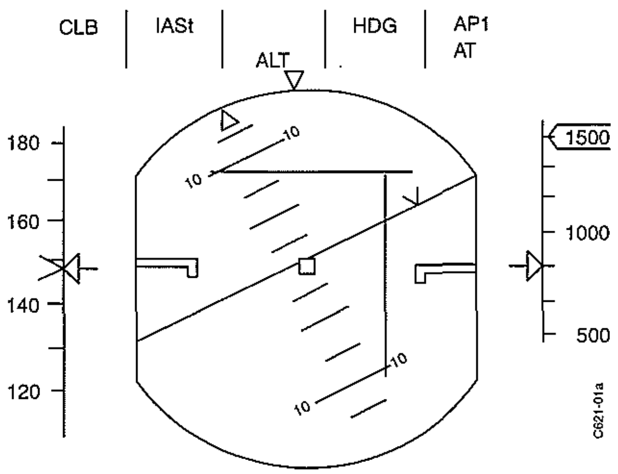


Fig. 2 Display #1: Conventional Flight Director display (cross bars). Command is up and to the right.

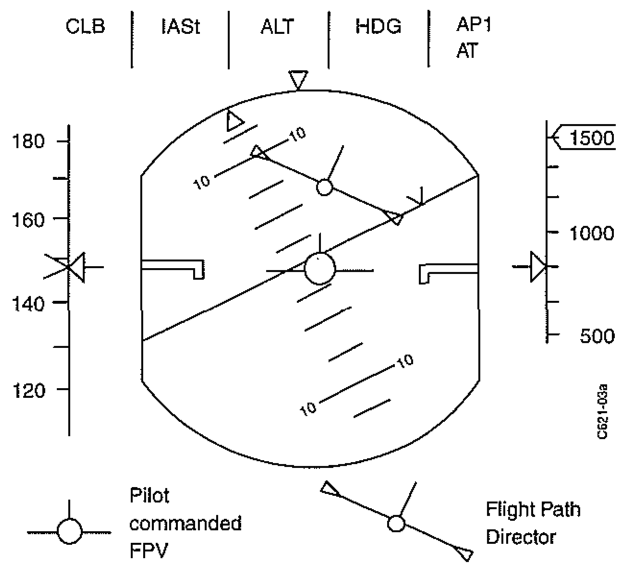


Fig. 4 Display #3: Flight Path Vector Display with "ghost aircraft" Flight Path Director. Command is up and to the right.

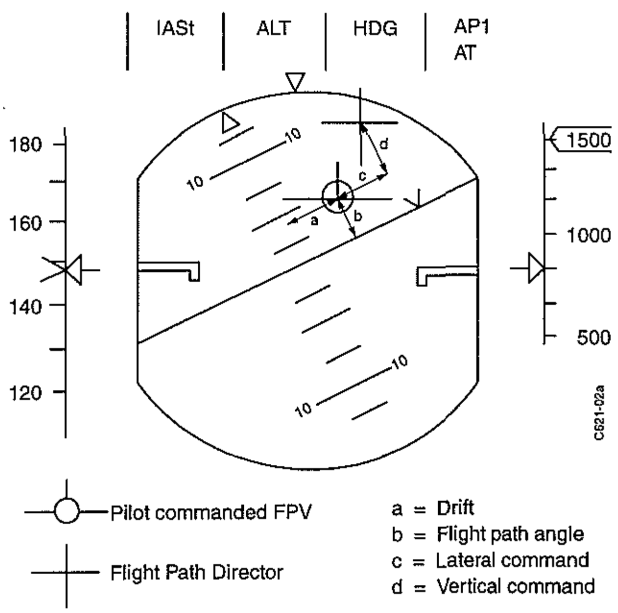


Fig. 3 Display #2: Flight Path Vector Display with Cross Flight Path Director. Command is up and to the right.

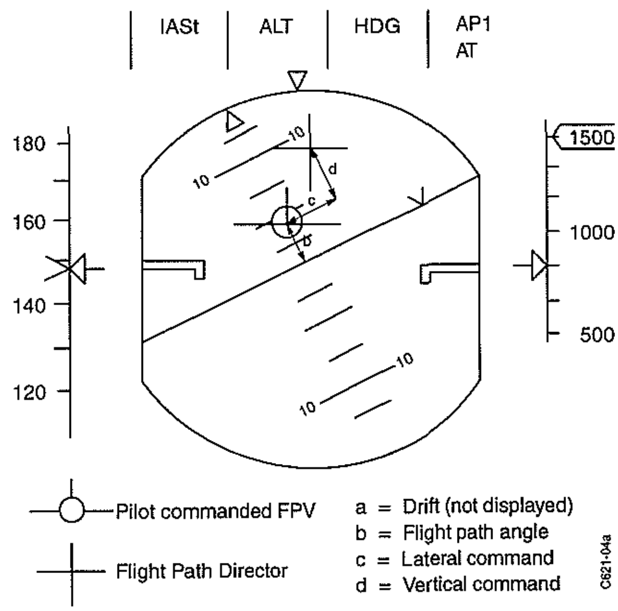


Fig. 5 Display #4: Flight Path Vector Display with Cross Flight Path Director without Drift. Command is up and to the right

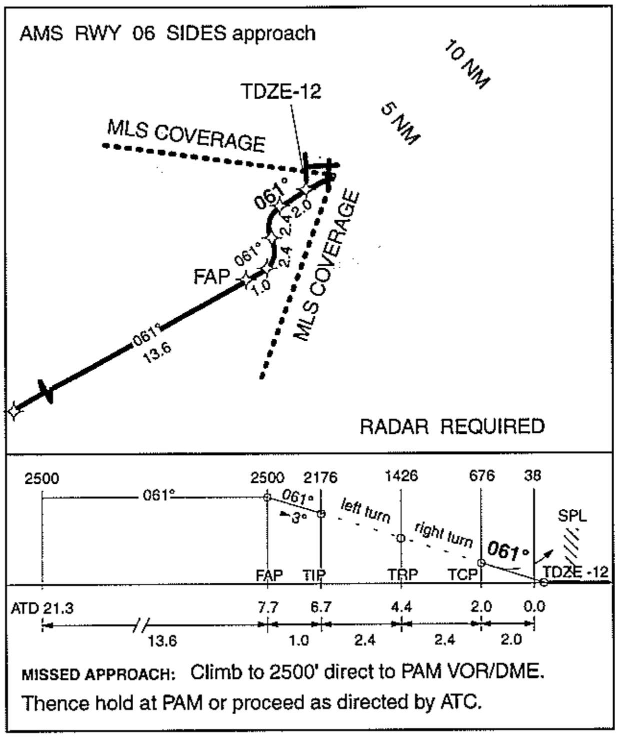


Fig. 6 Provisional approach plate for the AMS RWY 06 SIDES approach

C621-05a

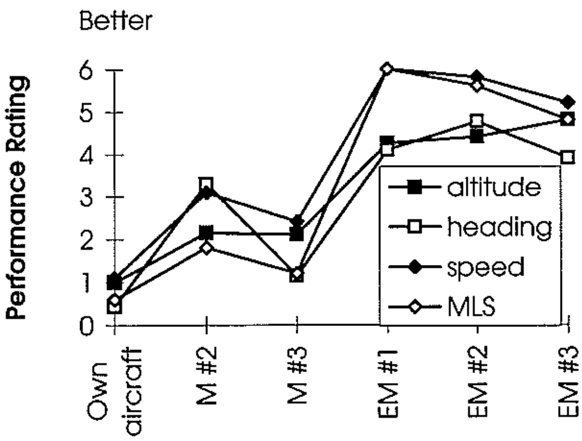


Fig. 7 Performance rating compared to base line P370-II

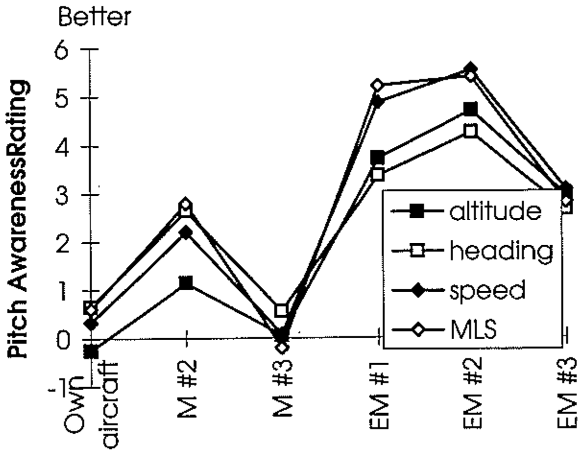


Fig. 8 Pitch awareness rating compared to baseline P370-II

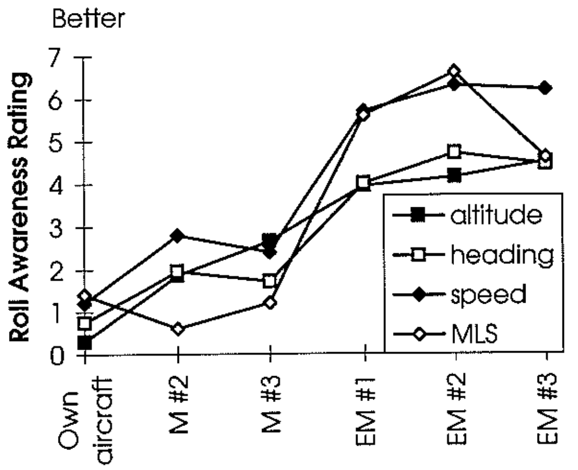


Fig. 9 Roll awareness rating compared to baseline P370-II

Legend	Condition
M #1	Manual, Display #1
M #2	Manual, Display #2
M #3	Manual, Display #3
EM #1	Enhanced Manual, Display #1
EM #2	Enhanced Manual, Display #2
EM #3	Enhanced Manual, Display #3

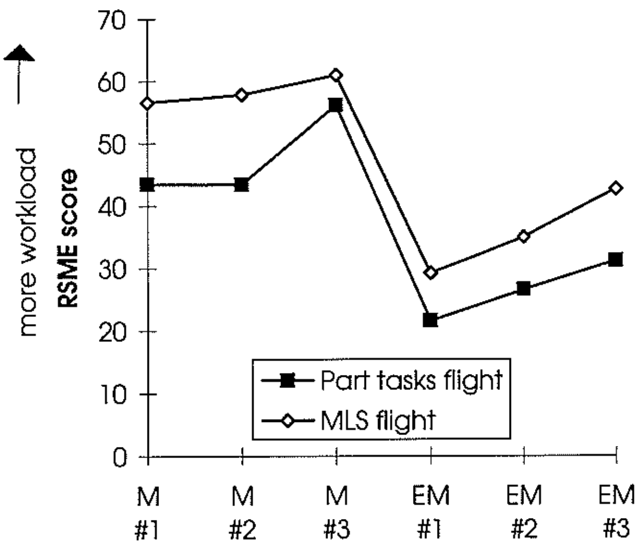


Fig. 10 RSME workload rating

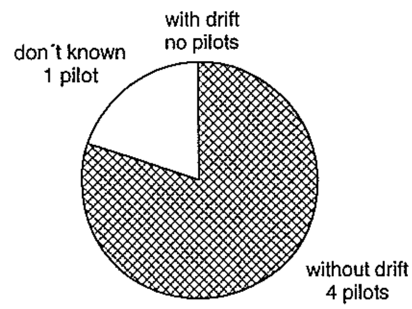


Fig. 11a Which is better for Manual control; with or without drift information?

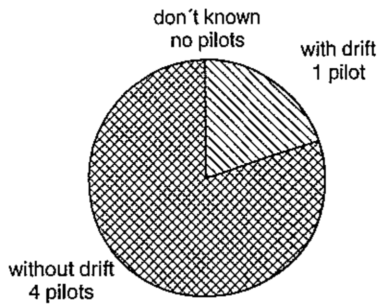
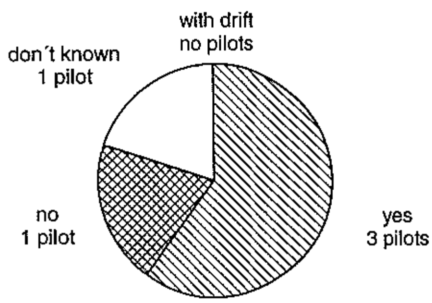


Fig. 11b Wich is better for Enhanced Manual control; with or without drift information?



C621-06a

Fig. 11c Would a drift indicator be helpful on the PFD?

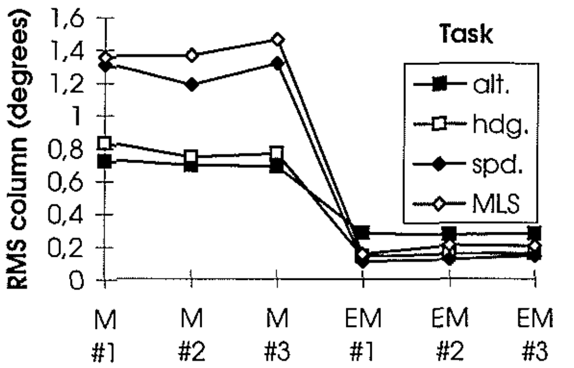


Fig. 12 Pilot Pitch input

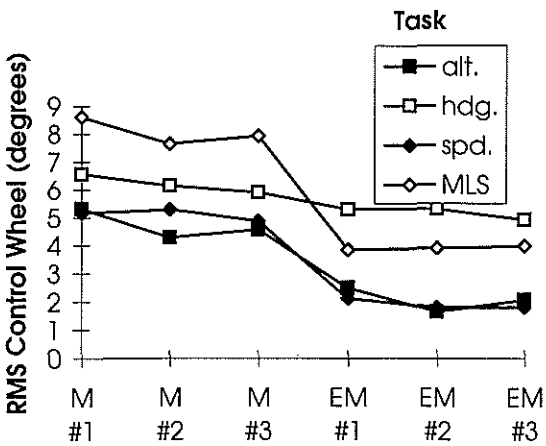


Fig. 14 Pilot Roll input

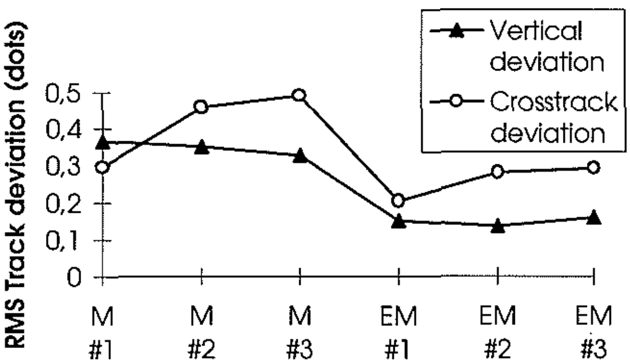


Fig. 13 Track deviations during Curved (MLS) approach

Legend	Condition
M #1	Manual, Display #1
M #2	Manual, Display #2
M #3	Manual, Display #3
EM #1	Enhanced Manual, Display #1
EM #2	Enhanced Manual, Display #2
EM #3	Enhanced Manual, Display #3

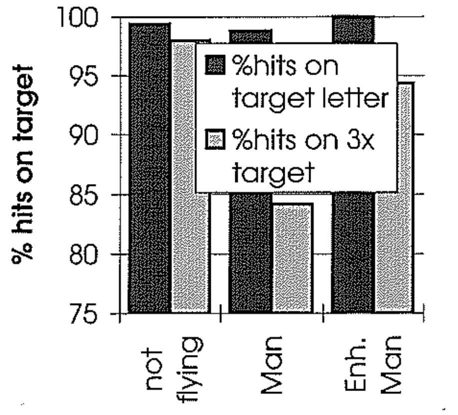


Fig. 15a Continuous Memory Task hits percentage

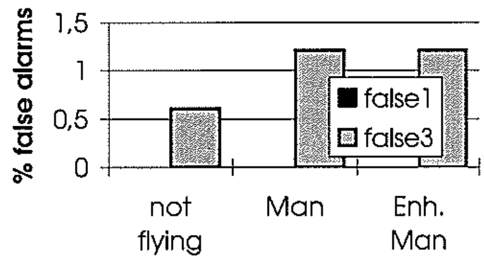


Fig. 15b Average number of false alarms

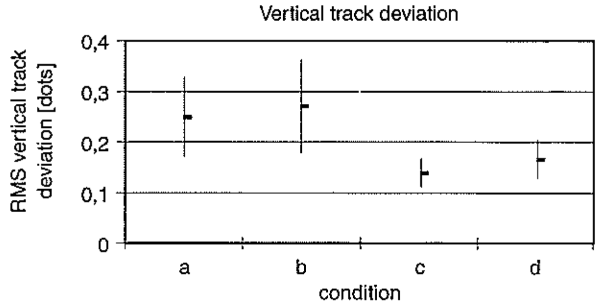


Fig. 16 Vertical track deviation; mean ± 1 standard deviation

a	Man	drift
b	Man	no drift
c	Enh Man	drift
d	Enh Man	no drift

C621-07a

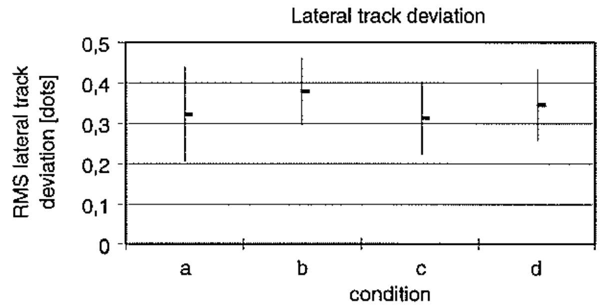


Fig. 17 Lateral track deviation; mean ± 1 standard deviation