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FLIGHT SIMULATION STUDIES ON THE FEASIBILITY OF LATERALLY SEGMENTED APPROACHES IN AN MLS ENVIRONMENT

by

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Abstract

On the moving base flight simulator of the NLR an investigation was carried out to establish a number of minimum approach parameters concerning laterally segmented approach paths, assuming that guidance was provided by an MLS facility. Seven laterally segmented approach paths with different turn angles and final intercept altitudes were flown manually with a simulated heavy transport aircraft in the final approach configuration. Results were obtained in terms of tracking accuracy, pilot effort ratings and pilot responses to a questionnaire. A subsequent simulation program was carried out recently, in which as new items were introduced: a more realistic simulation of the MLS environment (MLS coverage area and signal noise), implementation of aircraft configuration changes (flaps, landing gear). A third simulation program is prepared in which the interaction is emphasized between the air traffic controller and the flight crew. The pilot is vectored to a point within MLS coverage, from which he is expected to intercept a laterally segmented approach path using MLS-guided intercept procedures.

1. Introduction

The wide coverage sectors in both azimuth and elevation of the future Microwave Landing System MLS (See Fig. 1), which is intended to replace the current Instrument Landing System ILS, enables the introduction of non-straight-in approach paths(1). Although in fact each arbitrarily curved path can be defined, as long as it is within the coverage volume, it is expected that only a limited number of simple approach paths will be adequate for practical use.

The need of implementation of non-straight-in approach paths proceeds from:

- noise abatement needs,
- airspace restrictions,
- geographic conditions,
- fuel economy reasons.

With respect to the introduction of segmented approaches in the vertical plane, it has to be remarked that IFALPA - with respect to the FAA advanced notice of proposed rule making (ANPRM 74-12)- rejected approach procedures below 1500 ft, which require rates of descent in excess of 1000 ft/min or multi-segment descent paths. Therefore it is very unlikely that approach paths having multiple descent angles will be put forward as a primary application of the non-straight-in capability.

On the contrary the introduction of laterally segmented approaches seems to encounter less opposition. It was therefore decided to direct the simulation studies at the NLR, which were carried out under contract for the Department of Civil Aviation of the Netherlands (RLD) to the feasibility of laterally segmented approach paths. The studies are intended to support the work done by the ICAO All Weather Operations Panel (AWOP).

The intention of the investigations was not to find out what is ultimately practicable, but rather to determine what is acceptable with a view to standard airline routines, using the present-day type of guidance instrumentation, with only the most essential modifications and extensions. Although it is expected that these approaches will be flown automatically under operational conditions, it was decided to direct the investigations to manually flown approaches for the following reasons:

- If it is proved that a particular approach can be successfully carried out manually, it certainly can be done automatically in a more consistent way, with a higher degree of accuracy.
- It is difficult for a pilot to discern whether an automatically flown approach is acceptable or not, if his opinion is merely based on monitor function experience. On the contrary, if a pilot is convinced that he is able to do it manually, he surely will approve a procedure when it is performed automatically.

The aim of the first simulation study was to establish limits concerning the allowable turn angle to final and the minimum altitude for final intercept. Moreover the required provisions for guidance were investigated thereby. In a follow-up simulation study a realistic representation of the MLS environment (coverage areas and signal noise) was included and moreover aircraft configuration changes (landing gear, flaps) were implemented. The simulated approaches hereby were of the downwind-type.

2. Laterally Segmented Approach Paths

After an extensive discussion with ATC specialists a series of three different types of approach paths were established which satisfy the primary need for non-straight-in approaches. The various types are described by (See Fig. 2):

- oblique approach paths,
- parallel-offset approach paths,
- downwind-type approach paths.

In order to obtain approach paths which provide "all the way" guidance, the transition from one straight element to the next had to be developed further. This resulted in the insertion of curved segments serving as a connection between two straight segments. The shape of the curved segment was chosen circular. The use of circular transitions has several benefits, for instance: it yields rather simple mathematical expressions for the track deviation computations and moreover pilots are familiar with flying circular paths.

The bank angles during the turns can be kept low by a proper selection of the turn radius. In the present simulations a radius of 1.5 n.m. has been applied. The bank angle needed to proceed along a circular path, in a wind environment, is dependent on the momentary ground speed.

The applied geometry has the following features:

- the fixed ground-based patterns are advantageous for applications where noise abatement, airspace limitations or geographic circumstances play a role,
- the "all the way" guidance, due to the introduction of the circular arc transitions, yields a low variation in aircraft position at the moment of final intercept,
- a unique position determination along the approach path is possible through the use of the along track distance (ATD) parameter (Fig. 3). So a constant 3° glide path can be defined, that is maintained along both straight and curved segments during the descending phase of the approach.

3. Approach Path Guidance

3.1 Path deviation signals

For performing laterally segmented or curved approaches in an MLS environment, using present-day guidance and control equipment such as autopilot, flight director (ADI) and horizontal situation indicator (HSI), path deviation signals have to be generated which are similar to ILS localizer and glide slope deviation signals. In contrary to these ILS signals, which can be directly applied for guidance, the deviation signals for the segmented approach paths have to be computed on-board, originating from elevation, azimuth and slant range signals as received from the MLS and DME transmitters respectively.

The position of the aircraft with respect to a particular approach path is then determined by (See Fig. 3):

- along track distance (ATD), representing the distance-to-go, measured along the projected approach path on the horizontal plane,
- cross track deviation (η), being the horizontal distance from the nominal path,
- vertical path deviation (ξ), being the vertical distance from the nominal path.

The η and ξ deviation signals have to be reduced to angular quantities conform to ILS localizer and glide path deviations (as defined in (2)), understanding the curved path as straightened out along the runway centreline (See Fig. 4). For that purpose the calculated η and ξ were reduced - by means of the ATD - to angular deviations, σ and ε respectively.

3.2 Required signals for tracking guidance

Besides the substitution of the localizer and glide slope deviation signals by the computed σ and ε signals respectively, additional provisions had to be made with respect to the roll bar drive of the flight director for tracking of the curved segments.

Two additions have been made in order to obtain smooth tracking of a curved segment:

- a roll command signal was added in order to compensate for the circular flight path. The required bank angle along a circular track is dependent on aircraft ground speed (V_G) and turn radius (R), according to:

$$\varphi = \arctan \frac{V_G^2}{g\,R}$$

In Figure 5a this relation is shown graphically for a turn radius of 1.5 n.m.

As shown by the inserted figure 5b, the stall speed increase due to the bank angle bias is small for moderate bank angles (3% increase for $\varphi_o = 20°$).

- The roll command has to be initiated before the mathematical transition point. Therefore a lead distance for turn entry and turn exit was determined and included in the roll bar drive.

4. Description of the Simulated MLS

The simulated MLS azimuth and elevation transmitters have been assumed to be located at the usual ILS localizer and glide path antenna sites, while the DME antenna was supposed to coincide with the azimuth transmitter. The coverage areas for both azimuth and elevation signals have been defined according to the provisional specifications provided by ICAO, yielding sectors of 40 degrees to both sides of the runway centreline along a range of 20 n.m. (See Fig. 1). For the simulation of the MLS noise on the simulated guidance signals use was made of (3).

5. Test Simulation Facility and Test Data

The NLR has at its disposal a versatile moving-base flight simulator especially designed for research purposes. The main components are:

- a four-degrees-of-freedom motion system,
- a single-seat cockpit, interchangeable with a multi-crew (transport) cockpit,
- a visual system comprising a rigid three dimensional terrain model, representing an airfield with Category II lighting and a surrounding terrain. The model is viewed through a closed-circuit colour TV-system with collimating display,
- computing and recording facilities.

Visibility effects such as clouds, haze and fog are introduced by electronically altering the terrain image. The present simulations were carried out with the single-seat cockpit installed. This was merely due to the fact that at the time these investigations were performed the multi-crew cockpit was still under construction.

The test results used in the evaluation were based on both subjective and objective data.

Subjective data in terms of:

- pilot effort ratings,
- questionnaire responses (multiple choice system),
- pilot comments

Objective data concerning:

- recorded cross track and vertical path deviations,
- recorded aircraft state parameters,
- statistical data concerning tracking performance and control activity.

6. Instrumentational Provisions

A lay-out of the instrument panel as used in the simulator cockpit is depicted in Figure 6. The instrumentation applied is very usual for the present class of transport aircraft, except for the pictorial display.

Modifications to the flight director (ADI) and horizontal situation indicator (HSI) have been applied in order to imply the curved approach capability.
Another feature in the instrumentation is the presence of a turn annunciator light, warning the pilot that the turn was about to arrive or to terminate.
The necessary provisions as applied to the normal instrumentation will be discussed hereafter.

Flight director (ADI)
The following modifications have been adopted to the original flight director modes in order to realize the curved approach capability:

- The localizer and glide slope signals have been replaced by the computed σ and ε signals respectively.
- Along the curved segment, taking into account the lead distances for turn entry and exit, a bank angle bias signal φ_0 is added to roll bar channel. Either a constant φ_0 or a variable (e.g. ground speed dependent) bias signal can be applied.

Horizontal situation indicator (HSI)
In the usual ILS intercept mode the HSI displays the position of the aircraft relative to the extended centreline of the runway. In the present MLS mode the instrument indicates the position of the aircraft relative to the desired track of the particular approach path.
In the left DME window of the HSI the along track distance (ATD) was displayed instead of the usual DME distance.

Pictorial display
An 8 x 10 cm screen-size oscilloscope was used to provide additional guidance information. Horizontal and vertical path profiles could be displayed,while the aircraft position was depicted by a moving dot.

Marker beacons
When the ILS is replaced by an MLS, it is expected that also typical ILS features such as outer and middle marker beacons will disappear, consequently during the present simulation these markers were omitted.

7. Meteorological Conditions

Since an infinite number of weather conditions are conceivable during actual flight, a limited number of meteorological conditions had to be selected for the simulations.
The meteorological conditions for the approach are mainly defined by:

- cloud base and visibility,
- wind vector (magnitude and direction),
- wind shears (variation of wind vector with altitude),
- turbulence.

Three meteorological conditions were established for application. These conditions, given in Figure 7, yield successively deteriorating visibility conditions, while the effect of wind shears on the intercept accuracy of the final segment can be analyzed by comparing the results for conditions W_2 and W_3 with condition W_1.

8 Simulation Investigations

8.1 Preliminary investigation

When the feasibility of laterally segmented approaches is investigated, one of the major questions to be answered is:
"What is the minimum altitude where the turn to final has to be completed, possibly in dependency of the offset angle of the oblique segment?"
This question should be answered against the background of standard airline routines, originating from the presence of only slightly modified present-day guidance and control cockpit equipment.
For that purpose seven laterally approach paths were defined, having turn angles ranging from 45° to 180° in combination with altitudes at the final intercept point (FIP) between 400 ft and 1500 ft. In Figure 8 the investigated approach paths are shown.

The investigation on the NLR flight simulator was carried out using a simulated heavy transport aircraft (Boeing 747), since this type of aircraft is considered to be critical with respect to the curved approach capability.
Each approach started with the aircraft in the final approach configuration, established on its lateral track and glide path, which implied that no configuration changes (gear, flaps) had to be applied while performing the approach.
No restrictions with respect to azimuth and elevation coverage areas were considered during this investigation, moreover the hereby simulated guidance signals were free of noise.
The bank angle bias was determined by the nominal approach speed of 160 kt yielding $\varphi_0 = 14°$ and was kept constant during a turn.

Three pilots with extensive airline experience participated in this simulation program.
A total of 63 simulator flights were performed including 315 MLS test approaches and 126 MLS familiarization approaches. Each flight was divided into a familiarization part and a test part. It was composed as follows:

- 1 familiarization ILS approach
- 2 familiarization MLS approaches of the approach profile concerned
- 5 test MLS approaches of the same profile.

The weather condition was kept constant during one session. The pilot was only informed about the cloud base, runway visual range and surface wind.

Results of the investigation
According to the results of the questionnaire (Fig. 9a) the approach path profiles with the final intercept point (FIP) at 400 ft altitude were considered "unacceptable" regarding standard operation routines. The most important objection was that there is not enough time to stabilize on the final segment (Fig. 9b), leading to an unacceptable increase in pilot effort (Fig. 9c).
The opinion of the pilots was that the MLS-guided approach paths with low FIP altitudes may be useful to existing curved approaches, which are nowadays being performed merely visually (e.g. the Canarsie approach at Kennedy airport).

So far as approaches with the FIP at 1000 ft or above were considered, in more than 75% of the cases simply the qualification "acceptable" was attached to these approach paths (Fig. 9a), while in the remaining 25% of the responses an additional comment was given to the qualification "acceptable". This comment came from one pilot who stated that with full flaps the bank angle is normally restricted to 15°. Due to the effects of wind, however, the actual bank angle frequently exceeded this value.
Nevertheless the general opinion was that the average airline pilot will hardly need any practice to perform these approaches.

Furthermore the pilots stated unanimously that the magnitude of the angle of turn is unimportant; the only decisive parameter is the altitude at FIP, which finds expression in the questionnaire results presented in Figure 9d.
With respect to the instrumentational provisions the following remarks can be made:

- Depending on the type of the autopilot and flight director, provisions have to be made with respect to the roll channel in order to avoid large deviations during curved segment tracking. If a ground-fixed track has to be followed, the roll angle bias signal for roll control and roll bar drive has to be made dependent on the ground speed.
- The modified horizontal situation indicator (HSI), providing the aircraft position relative to the nominal track, appears to be a useful instrument for monitoring. Also the presence of the turn annunciator was appreciated.
- If the above mentioned monitoring aids are available there is no need of an additional pictorial display, so far as the tracking of this very simple type of approach is concerned. However, in case of more complex approach paths and moreover during the interception phase of the present curved approach paths a pictorial display system might be very useful.

An extensive description of the results of this investigation is presented in (4).

8.2 Follow-up simulation program

Originating from the results and conclusions obtained from the first simulation investigation a follow-up program was defined. In this program the following new items were introduced:

- a more realistic simulation of the MLS environment by implementing the MLS azimuth and elevation coverage areas, as specified by ICAO, and moreover by the addition of noise to the simulated MLS guidance signals.
- aircraft configuration changes (landing gear, flaps) during the approach were taken into account.
- Moreover instead of a heavy transport aircraft, a twin-engined jet transport in the medium weight class (Fokker F-28) was simulated. The reason for using a different type of aircraft was that an extensive simulator model, allowing configuration changes, was available for the F-28 aircraft but not for the heavy transport aircraft.
- The constant bank angle bias signal φ_0 in the flight director roll bar channel was replaced by an airspeed dependent signal.

In this simulation program only one approach path type was considered namely the downwind-type approach. The reason for this selection was twofold:

- firstly, the downwind-type provides for sufficient manoeuvring to enable a study of destabilization aspects during segment transitions and moreover it allows an analysis of path tracking performance. The downwind-type could be considered in this respect as a worst case within the proposed types of laterally segmented approach paths.
- secondly, it yields a pattern that will be undoubtedly used in future air traffic, and represents as such a realistic application.

During the simulations 6 different downwind approach profiles were generated, having different combinations of final segment length (3,4,5 and 6 n.m.) and lateral downwind distance (3 and 4 n.m.). A survey of these six patterns is presented in Figure 10.
The final length of 3 n.m. was based on the minimum value established during the first investigation. The minimum lateral distance of 3 n.m. was determined by the radius (1.5 n.m.) of the curved segment.
As shown two initial approach altitudes were considered hereby, enabling the positioning of the glide path intersect point on the curved segment.

Approach procedure for the downwind-type approaches

A picture of the MLS downwind-type approach procedure is shown in Figure 11. The pilot proceeded on downwind until he was cleared to initiate the turn. Turn initiation was announced by the turn annunciator, which was activated about 2 seconds after the flight director roll command for turn entry was given. The annunciator light switched-off again about 2 seconds before the turn exit command appeared. At the moment of initiation of the first turn, the image on the pictorial display was automatically switched-on. Each approach was completed with a full stop landing.

Reference ILS approach procedure

An ILS approach, carried out at the beginning of each simulation session, served as a reference case for the subsequent MLS downwind approaches. The ILS procedure is shown in Figure 12. The initial localizer intercept angle was 40°. The sensitivities for ILS localizer and glide slope deviations were equal to those of the simulated MLS downwind approaches.

Experimental design

The test program was divided into different sessions, each session including a normal ILS approach followed by a series of five MLS downwind approaches.

The five MLS downwind approaches in each test session were arbitrarily selected with respect to the combination of profile type and weather condition.
There were six MLS downwind profiles and three different weather conditions considered. Since each combination of profile type and weather condition was flown five times by each of the three pilots, a total amount of 270 simulated MLS runs were carried out during 54 test sessions.

Before each run was started the pilot was informed about the cloud base, runway visual range and surface wind, but he had no knowledge of the windshear pattern as presented in Figure 7. He was also not informed about the downwind profile he was expected to fly. Just at the turn initiation point (TIP) the image on the pictorial display was switched-on, showing him the shape of the demanded approach path.

Three pilots participated in the test program, their flight experience on twin-engined jet transport aircraft ranged from 800 to 1200 hours.

Test results

The main points resulting from the pilot comments can be summarized as follows:

- Objections were made to the flap/speed schedule as used in the curved approach procedure. The pilots did prefer an intermediate flap setting before selecting full flaps instead of directly selecting full flaps at glide path interception. Moreover they preferred to delay the selection of full flaps until the aircraft was on the straight final approach track.
- The pilots stated that all, under Cat. II weather conditions flown, downwind approaches were easy to perform manually. Under the current ILS related operational regulations, however, manually flown approaches are not allowed under these weather conditions. In answering the relevant questions the pilots often referred to this conflicting situation.

From the effort ratings it appeared that no significant differences in effort exist between the downwind approaches mutually. A comparison with the ratings given for the ILS approach learned that only for the item concerning the total approach execution slightly higher effort ratings were given for the MLS approaches.

The main points resulting from the analysis of the questionnaire responses will be discussed briefly below.
The pilot opinion about the acceptability of the MLS approaches,with respect to future implementation in the standard airline operational routines,has been expressed by the response scores shown in Figure 13a. According to the response scores, the profiles 3,5 and 6 - having final lengths of at least 5 n.m. - were qualified "acceptable" (response score > 90%). The slightly lower scores for profiles 2 and 4 (approx. 75%) were, according to the pilot comments, mainly due to the relatively short length of the final segment of profile 2 (4 n.m.)and to the insufficient spacing between the moments of turn initiation and glide path intercept of profile 4.
Profile 1 was disapproved; 50% of the responses read "unacceptable". This was attributed to the unfavourable path geometry of profile 1, yielding an approach path of which the turn from downwind to final partly lies out of MLS (elevation) coverage (See Fig. 10).

In the questionnaire the pilots were also asked to give an estimation of the altitude at which stabilization on the track for the final approach was achieved. It appeared that stabilization occurs after final intercept when the altitude margin between glide path intersection and final intercept point is less than 750 ft. In other words, if stabilization at FIP is desired an altitude margin between GPI and FIP of at least 750 ft is required.

According to the responses given to the question concerning the bank angle on the curved segment (Fig. 13b), the magnitude of the bank angle was considered acceptable in more than 80% of the cases. The score for the response "marginal acceptable", varying between 10 and 20%, was mainly due to the fact that the curved segment was partially flown with full flaps.

A comparison between the control activities (aileron, elevator) did not show significant differences between the straight part of the ILS and either the straight or curved segments of the MLS downwind approaches.

As far as tracking performance is considered it appears that for the straight parts the performances are equal for both MLS and ILS approaches. However, the lateral tracking errors for the curved segment are obviously higher and are, as appears from data for various weather conditions, strongly dependent on the magnitude of the wind experienced during the curved segment.

For further details concerning the results of this simulation investigation is referred to(5).

9. Present and Future Activities

9.1 General

The simulation studies carried out so far have provided more insight, from a flight technical point of view, in the feasibility of carrying out laterally segmented approaches.
As a next step a study is conducted, dedicated to the implementation aspects of laterally segmented approaches into the air traffic control (ATC) environment.

MLS not only allows the execution of curved or segmented approach paths, it also can provide for guidance during the approach path interception phase. Within this scope the design and implementation of MLS-guided interception techniques, which can be applied to the aforementioned types of approach paths, are subject of a present investigation.

9.2 Proposed methods of approach interception

Three different methods are distinguished hereby:

- Procedural interception
- Minimum fuel/time interception
- Automatic standard interception after vectoring

- Procedural interception

The aircraft enters the MLS-sector according to a standard arrival (STAR). At MLS-sector entering, an intercept trajectory is generated automatically by the on-board computer to a defined fixed point on the approach path.
For the prevailing main traffic flows standard interception trajectories have to be defined.
The procedural interception, which can be executed without intervention of the air traffic controller, can be used e.g. in case of a radar or radio failure.

The procedural intercept point P (See Fig.14^a) shall be located not less than 8 n.m. (along track) before the threshold. Interception is performed via one of the two indicated interception circles.

- Minimum fuel/time interception

If the air traffic intensity allows, a minimum fuel/time interception can be carried out. The aircraft is hereby vectored until it is inside the MLS-sector (See Fig. 14^b). From an arbitrary position, that may be on the MLS-sector boundary, the aircraft is automatically guided to a fixed point F on the approach path (situated minimum 3 n.m. before threshold) via the shortest route. This minimum fuel/time interception is similar to the procedural interception, the only difference is that the air traffic controller can vector the aircraft to a desired position before it is released for interception.

- Automatic standard interception after vectoring

The method of automatic standard interception after vectoring has been initially selected as a subject for further investigation.
This method is intended to be applied in continuation of the radar vectoring process. The aircraft is vectored inside the MLS-sector to a point where the air traffic controller is convinced that no further vectoring instructions are required. The aircraft is then cleared to intercept the approach path according to a standard interception procedure, which can be preprogrammed in the on-board guidance computer. The demanded interception trajectory, beginning at the end-of-vectoring point (EOV) is depicted on the pilots navigation display after the pilot has pushed the "intercept button".

The standard interception procedure has to satisfy the following criteria:

- the resulting interception route shall be unique and rational
- interceptions have to be applicable to the proposed approach path types (depicted in Fig. 2).
- from practically each position within the MLS coverage area the system shall be capable of providing a usable interception track.
- interception tracks have to be composed of both straight and circular segments. For the present, the radius of circular segments has been established on 2 n.m.
- the length of the intercept track and the remaining part of the approach path shall not be less than 8 n.m. in order to guarantee sufficient time for stabilization.
- a distance of not less than 3 n.m. shall be flown along the straight final segment of the approach path.

In figure 15 two possible solutions have been indicated for the method of interception after vectoring. In figure 16 a number of example interception tracks for the fixed intercept angle technique has been depicted, for different aircraft positions and courses.

9.3 Intended simulation studies

For the method of automatic standard interception after vectoring a digital computer simulation is prepared in which various concepts will be evaluated. Use will be made hereby of an interactive computer program. For various aircraft positions and courses interception tracks will be computed and shown on a graphic display. Different interception methods can be evaluated for the various approach path types.

The main objectives in the design of an applicable interception method are:to keep the traffic situation orderly and predictable for the air traffic controller.
Finally, the most promising interception method will be investigated further during flight simulator trials.

10. Concluding Remarks

It is recognized that there are distinct flight technical differences between flying a conventional ILS approach and approaching along an MLS-guided laterally segmented approach path. In case of an ILS approach the condition of stabilization - in terms of being established on the localizer - can only be satisfied after the aircraft is aligned with the extended centreline of the runway. Due to the small beam width of the localizer signal, interception of the localizer beam has to be performed long before touchdown. On the contrary, proportional guidance is provided by MLS in both azimuth and elevation. Therefore stabilization can be achieved long before the aircraft arrives at the extended centreline, thus allowing shorter lengths of the straight final part of the approach.

Originating from the approach path geometry and guidance presentation as applied during these simulation studies, the general conclusion is that the acceptability of a particular approach path only depends upon the length of the last straight final segment. The angle of turn is not a decisive parameter.

Laterally segmented approaches have to be regarded as impracticable with respect to IFR standard airline operations, if the length of the last final segment is much less than 3 n.m. (final intercept point at 1000 ft), for the present state of the art of flight control systems.

Although for IMC operations approach paths with final segment lengths of less than 3 n.m. have been disapproved, MLS paths with substantially shorter lengths are estimated to be of great use for the support of curved approaches which are nowadays carried out completely visually. As an example the Canarsie approach at Kennedy airport was mentioned.

The pilots considered the approaches in most cases acceptable, because the profiles were easy to fly. In a number of cases, however, the procedures were in violation of the present - on the use of ILS based - operating rules of the civil aviation authorities. This applies particularly to the fact that frequently the roll-out on the straight final segment was accomplished at an altitude appreciably lower than the usual minimum stabilization altitude for ILS under IMC.

According to the participating pilots, the average airline pilot will hardly need any practice to perform these approaches. However, the following remarks were made:

- there must be a sufficient spacing between the moment of glide path capture and the moments of turn initiation and turn completion.
- According to present procedures for normal ILS approaches the selection of full flaps takes place after the aircraft has been stabilized on the localizer. In case of curved MLS ap-

proaches there is no need - from a guidance point of view - of delaying the selection of full flaps until the aircraft has been aligned with the runway centreline. However, from flight operational considerations restrictions may be imposed upon the manoeuverability of the aircraft in the landing configuration.

These restrictions may possibly be removed, if the approaches will be carried out automatically.

The need of a pictorial display as a monitoring aid was not obvious, since the modified horizontal situation indicator (HSI) satisfied the monitoring demands for these relatively simple approach path configurations. During the interception phase of the considered approach paths, however, a navigation display will probably be indispensable. Within this scope the navigation display of the electronic flight instrument systems (EFIS) may possibly yield a useful monitoring aid.

The simulation studies carried out so far mainly emphasized the flight technical aspects of the laterally segmented approaches. As a next step a simulation study is prepared at the moment, which will be directed to the interception techniques of these approach paths, thereby taking into account the air traffic control aspects.

11. References

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5. Erkelens L.J.J. Flight simulation tests of downwind-type approaches in an MLS environment. (NLR report to be published).

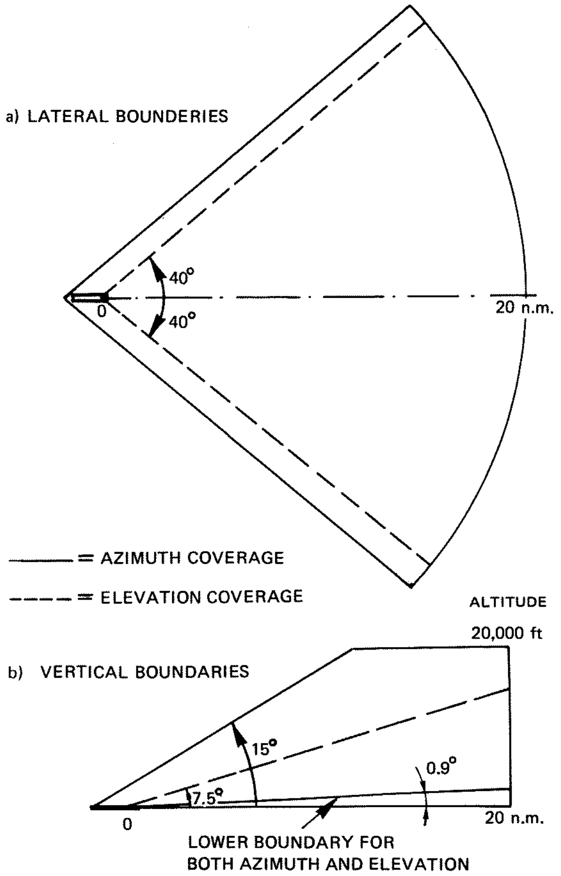


Figure 1. MLS azimuth and elevation coverage volumes

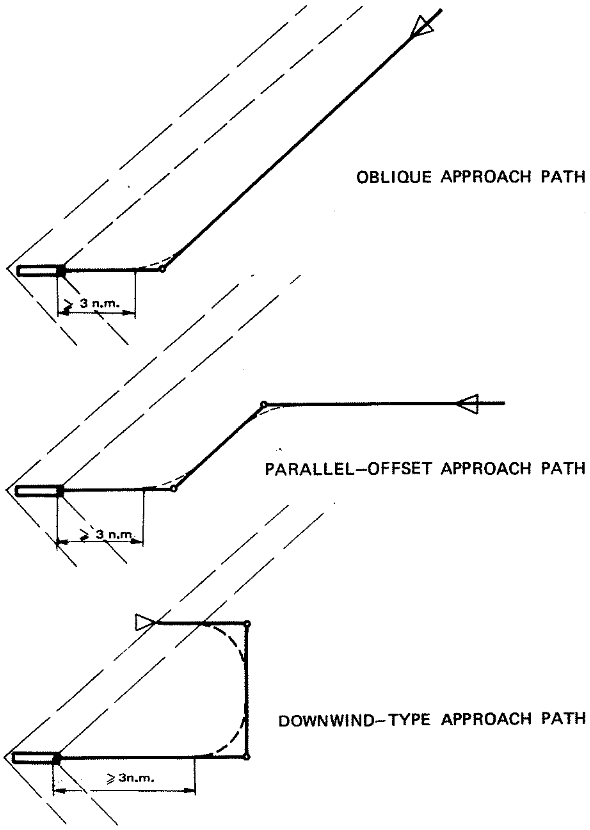


Figure 2. Proposed types of approach paths,

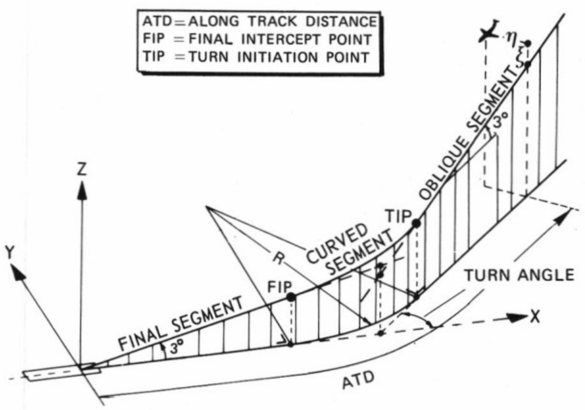


Figure 3. Lay-out of a laterally segmented approach path

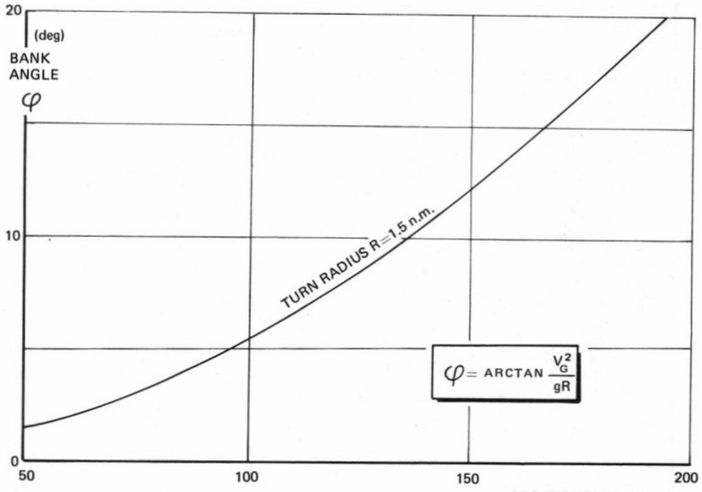


Figure 5^a. Required bank angle as a function of ground speed for a turn radius of 1.5 n.m.

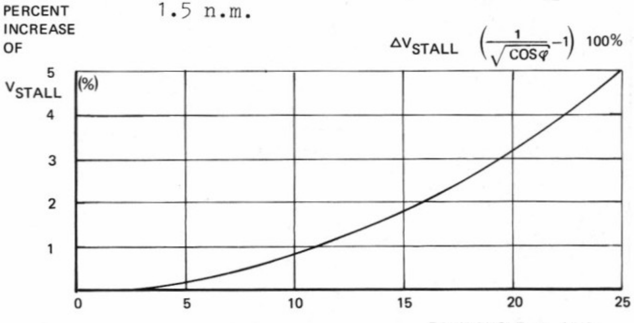
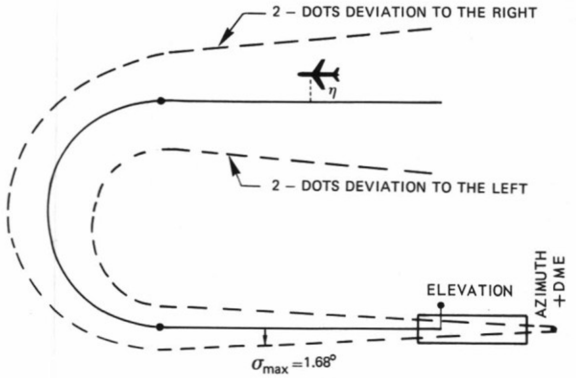
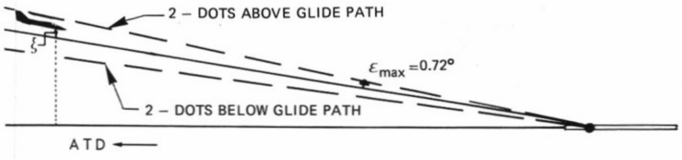


Figure 5^b. Increase of stall speed due to bank angle



A) SCALING OF THE LATERAL TRACK GUIDANCE



B) SCALING OF THE VERTICAL TRACK GUIDANCE, PRESENTED IN THE UNFOLDED VERTICAL PLANE

Figure 4. Scaling of the lateral and vertical track deviations

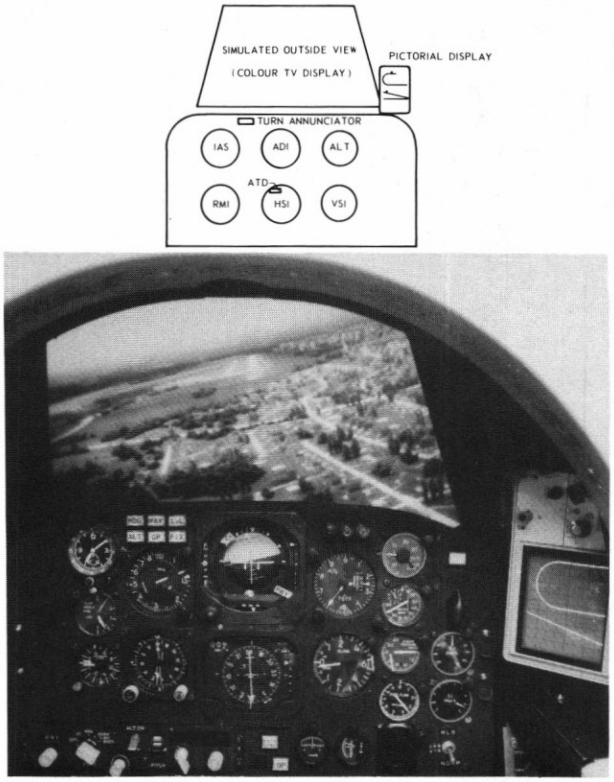


Figure 6. Picture of the instrument panel, including the pictorial display and simulated outside view

CONDITION	W_1	W_2	W_3
CLOUD BASE	152 m	60 m } CAT I	30 m } CAT II
RVR	1200 m	800 m } CAT I	400 m } CAT II
WIND ANGLE WITH RESPECT TO RUNWAY CENTRELINE	30°	30°	30°
TURBULENCE	MODERATE	MODERATE	MODERATE
WINDPROFILE			

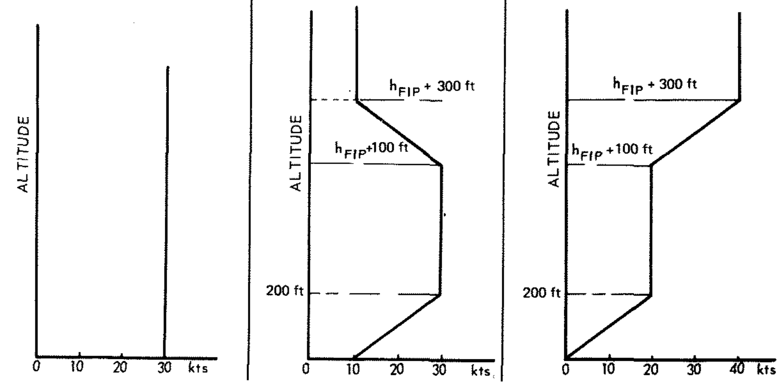


Figure 7. Definition of the meteorological conditions

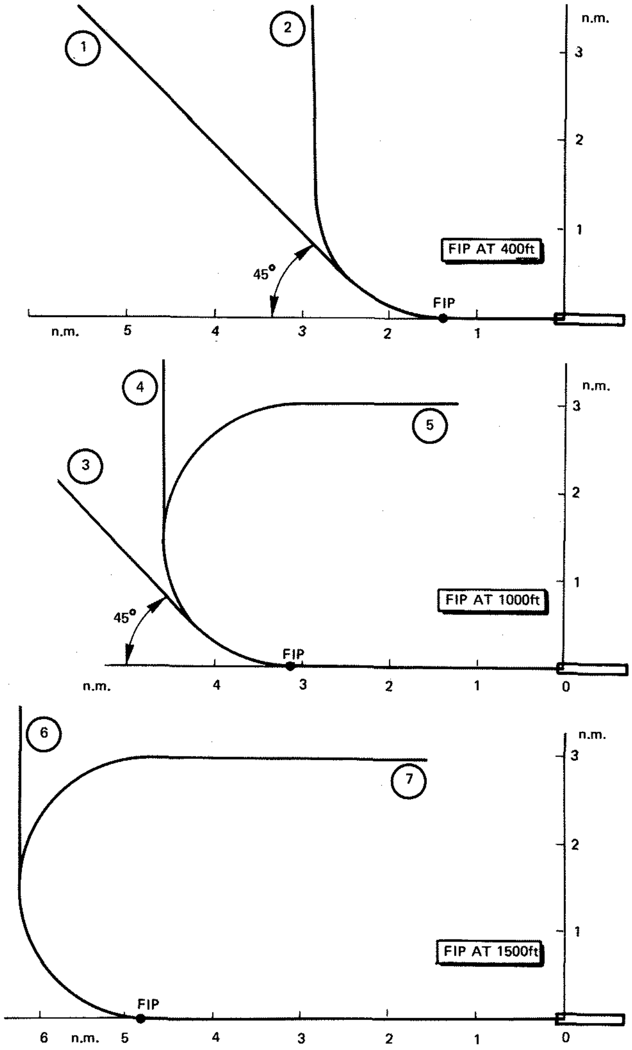
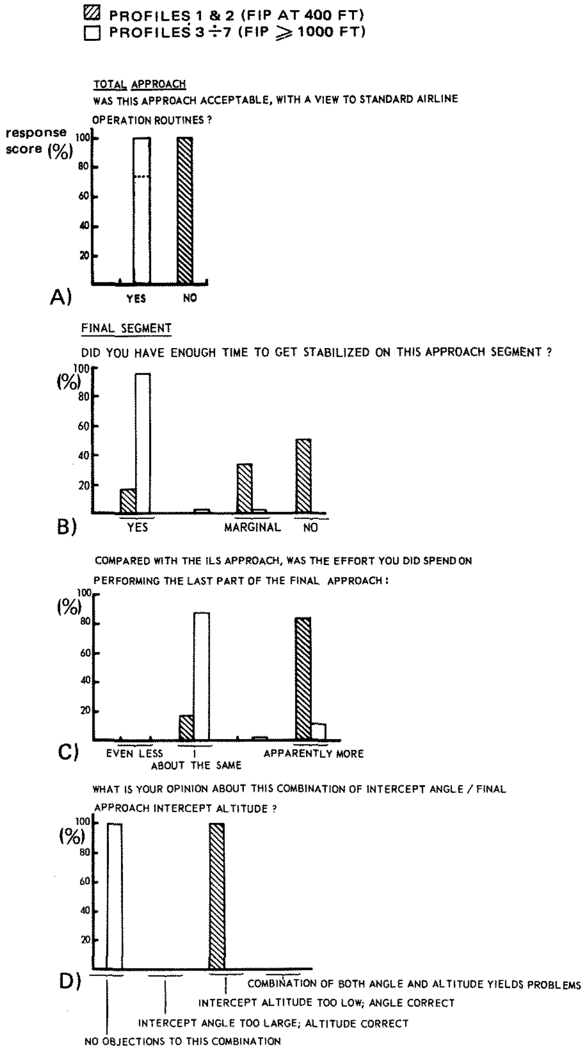


Figure 8. The investigated approach path profiles



TOTAL APPROACH

WAS THIS APPROACH ACCEPTABLE, WITH A VIEW TO STANDARD AIRLINE OPERATION ROUTINES ?

FINAL SEGMENT

DID YOU HAVE ENOUGH TIME TO GET STABILIZED ON THIS APPROACH SEGMENT ?

COMPARED WITH THE ILS APPROACH, WAS THE EFFORT YOU DID SPEND ON PERFORMING THE LAST PART OF THE FINAL APPROACH :

WHAT IS YOUR OPINION ABOUT THIS COMBINATION OF INTERCEPT ANGLE / FINAL APPROACH INTERCEPT ALTITUDE ?

Figure 9. Some questionnaire results

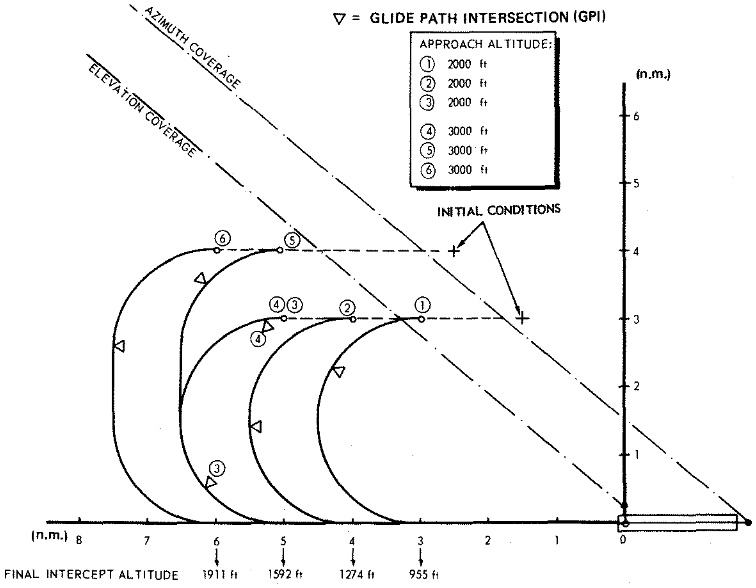


Figure 10. MLS downwind-type approach profiles considered during the follow-up investigation

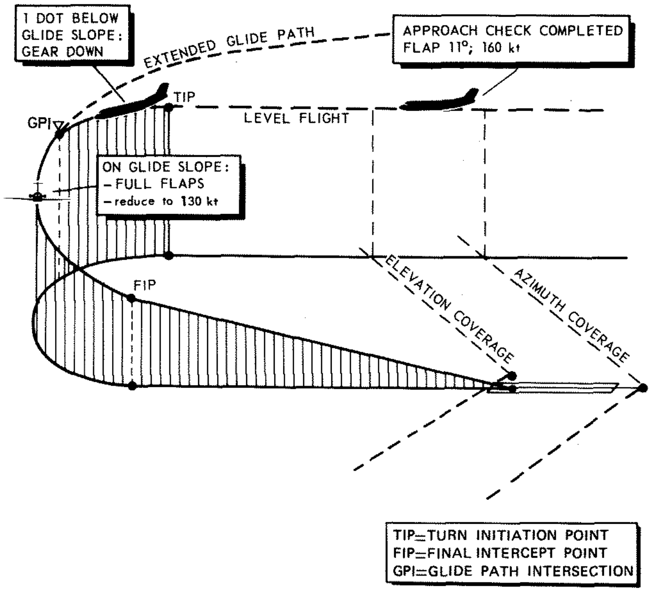


Figure 11. MLS approach procedure

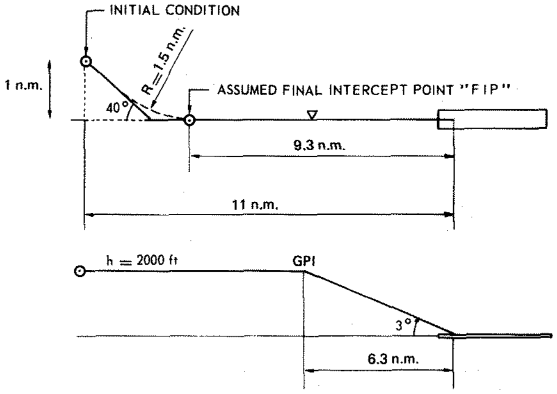
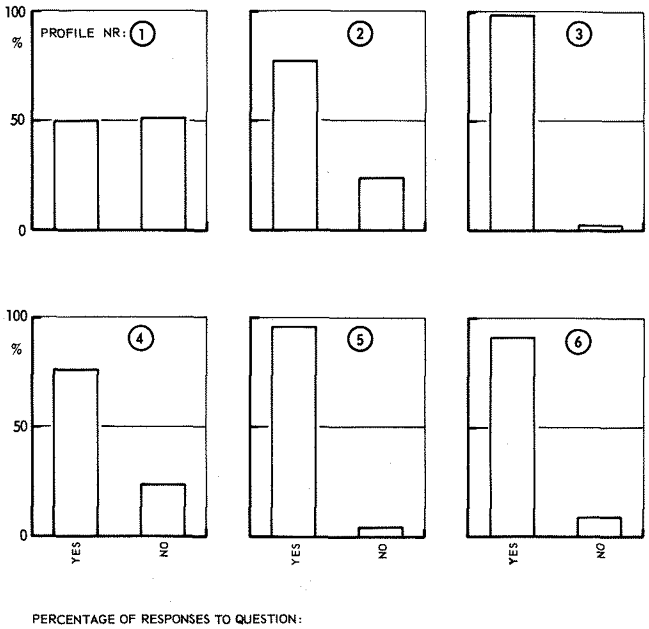


Figure 12. Reference ILS approach

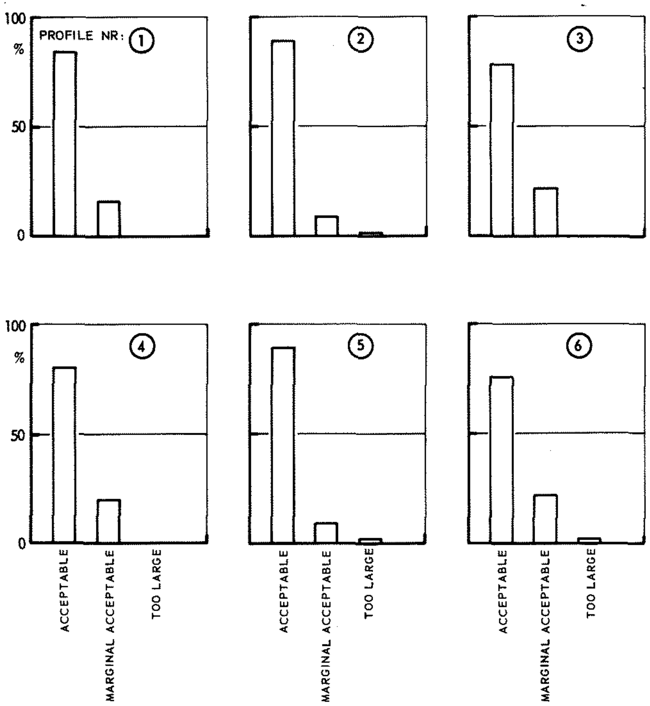


PERCENTAGE OF RESPONSES TO QUESTION:

TOTAL APPROACH

WAS THIS APPROACH ACCEPTABLE, WITH A VIEW
TO STANDARD AIRLINE OPERATION ROUTINES?

Figure 13^{a}. Questionnaire results

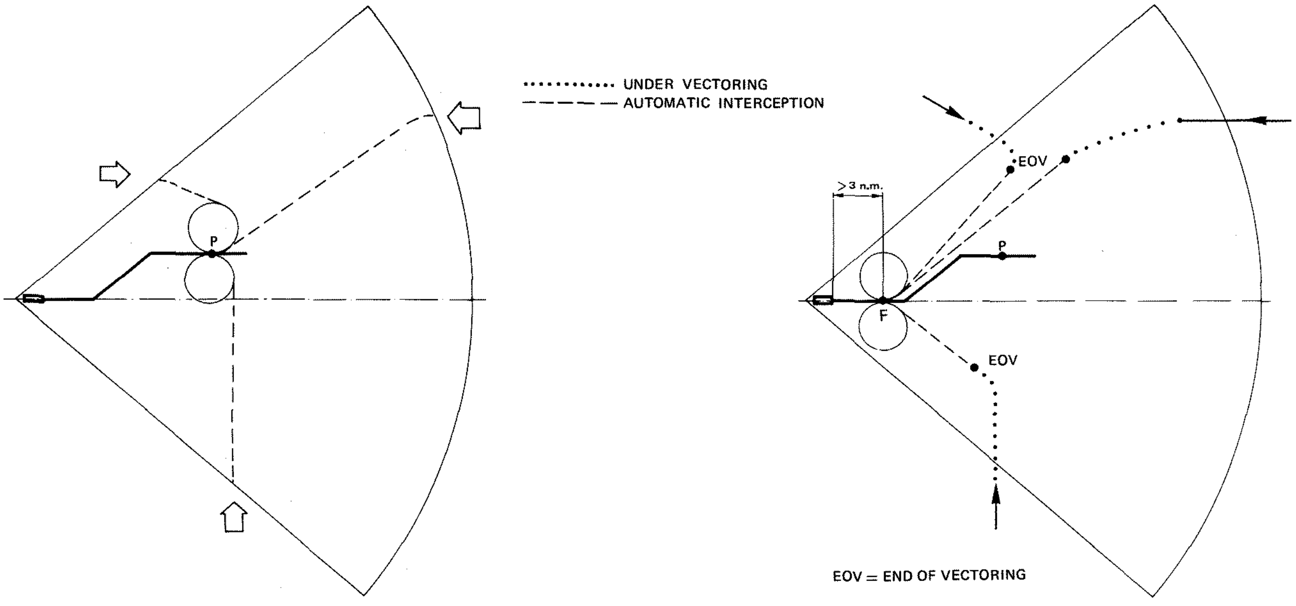


PERCENTAGE OF RESPONSES TO QUESTION:

CURVED SEGMENT

WAS THE MAGNITUDE OF THE BANK ANGLE REQUIRED
FOR TRACKING THE CURVED SEGMENT?

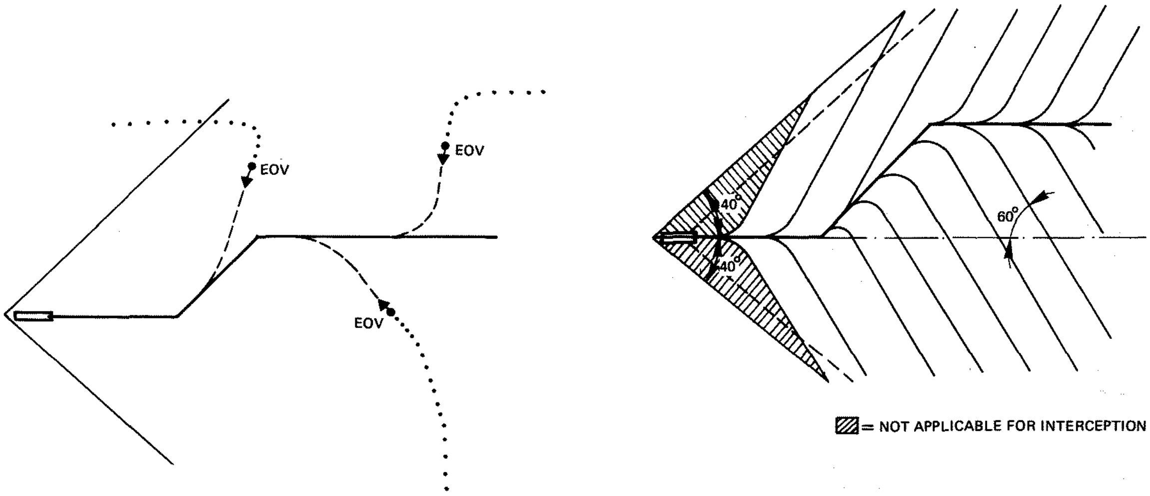
Figure 13^{b}. Questionnaire results



A) PROCEDURAL INTERCEPTION

B) MINIMUM FUEL/TIME INTERCEPTION

Figure 14. Schematic representation of the procedural and the minimum fuel/time interception methods



A) "PRESENT COURSE" INTERCEPTION

B) FIXED INTERCEPT ANGLE (60°)

Figure 15. Two examples of the automatic interception method after vectoring

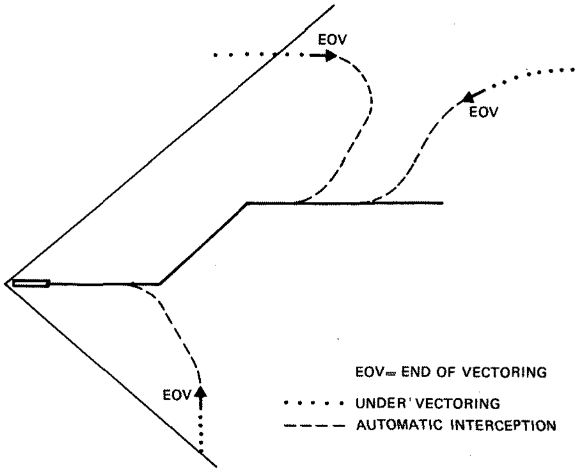


Figure 16. Illustration of possible interception tracks for the fixed intercept angle method