ICAS-92-1.4.2

FLIGHT SIMULATOR RESEARCH INTO ADVANCED MLS APPROACH AND DEPARTURE PROCEDURES

by
Louis J.J. Erkelens *
Jan-Hein van Dronkelaar **

National Aerospace Laboratory NLR
Flight Division
Amsterdam, The Netherlands

Abstract

A flight simulator program was carried out on NLR's Research Flight Simulator (RFS) with 19 airline crews to evaluate various test scenarios concerning curved approaches and departures. The test program was flown under full MLS guidance with a simulated Boeing 747-200 aircraft. The scenarios included MLS procedures for both the New York Area (John F. Kennedy International and La Guardia Airports) and Amsterdam International Airport Schiphol. Four curved approaches and two MLS departures have been evaluated. *Special features of the tests were:* simulated failures occurring during curved approaches. Crew ability to detect insidious failures and to respond to them were investigated. Crew performance and perception data were also measured in case of a simulated failure of the flight management computer during the execu-tion of a curved approach.

Since the captain's side of the flight deck had been equipped with EFIS displays (primary flight display and navigation display), whereas only electro-mechanical instruments were available at the first officer's station, results have been obtained for both glass cockpit aircraft and aircraft equipped with electro-mechanical instruments. A total of 350 MLS procedures were flown during the test program. The experimental results consisted of both objective and subjective data. Objective data concerned statistical data of path deviations, aircraft state and control variables. Subjective data were derived from questionnaire responses and pilot comments.

List of symbols and acronyms

ADI	Attitude Director Indicator
ATD	Along Track Distance
AZ	MLS Azimuth angle
CDI	Course Deviation Indicator
CDU	Control Display Unit
CTD	Cross Track Deviation
DH	Decision Height
DME/P	(Precision) Distance Measuring Equipment
EFIS	Electronic Flight Instrument System
EL	MLS elevation angle
FAA	U.S. Federal Aviation Administration
FAP	Final Approach Point
F/D	Flight Director
FMC	Flight Management Computer
F/O	First Officer
g	acceleration due to gravity
HSI	Horizontal Situation Indicator
ILS	Instrument Landing System
MLS	Microwave Landing System
ND	Navigation Display
NLR	Nationaal Lucht- en Ruimtevaart-laboratorium (National Aerospace Laboratory)
PF	Pilot Flying
PFD	Primary Flight Display
PNF	Pilot Not Flying
R	turn radius
RFS	(NLR) Research Flight Simulator
RLD	Rijksluchtvaartdienst (Netherlands Department of Civil Aviation)
SID	Standard Instrument Departure
TCP	Turn Completion Point
TIP	Turn Initiation Point
V_G	Ground speed
VTD	Vertical Track Deviation
φ	Bank angle

1. Introduction

For more than four decades the present Instrument Landing System (ILS) has served as the world-wide standard precision approach and landing aid in civil aviation.

Because of several inherent system limitations a new system has been developed, capable of coping with the requirements for future air traffic management.

ICAO selected the Microwave Landing System (MLS) to be the successor of ILS. According to the ICAO ILS-MLS transition plan, MLS will become the primary landing aid from January 1st, 1998.

The wide signal coverage of MLS, in both azimuth and elevation, allows new flight procedures to be defined, taking into account such matters as: airspace restrictions, obstacle clearance and noise abatement.

Research on the development of new flight procedures for MLS is conducted at the National Aerospace Laboratory NLR in Amsterdam and other institutions[1..18]. Results of the NLR studies[†] are submitted to ICAO and RTCA.

Under a contract awarded by the US Federal Aviation Administration (FAA) in 1989 an extensive flight simulation program was carried out on NLR's RFS. The objective of this program was to evaluate and demonstrate the operational feasibility of manually flown (F/D aided) curved approaches for wide-body aircraft under CAT II conditions[17].

In 1991, under a joint contract between FAA and the Netherlands Department of Civil Aviation (RLD), a subsequent flight simulation program was completed on advanced applications of MLS[18]. The present paper concerns the latter simulation program.

2. *Test Program Overview*

The test program was carried out on the Research Flight Simulator (RFS) which was programmed with a wide-body aircraft simulation model representing the characteristics of a Boeing 747-200.

Due to its large mass and inertia and the higher

---

* head flying qualities and flight control systems group

** research engineer

range of approach speeds, it is assumed that this type of aircraft yields a worst case situation with respect to flying curved flight paths. Twenty airline crews had been scheduled for these tests, however, due to a cancellation only 19 crews actually participated. The pilots came from 10 different airlines, from both USA and Europe. Totally 350 curved MLS approaches and departures have been flown during the simulation program. 11 percent of the tests were corrupted with simulated insidious failures, while 7% of the tests were corrupted with obvious failures.

All procedures were hand-flown using flight director guidance. Since the flight simulator cockpit had been equipped on the left hand side with EFIS displays and on the right hand side with conventional electro-mechanical instruments, experience was gained with both types of instrumentation.

3. Test objectives

- The primary purpose of the tests was to expose crews to MLS-based curved path approach and departure procedures, which have been determined to be beneficial from an ATC point of view.
- To collect pilot perception and performance data while flying these curved path procedures.
- To study the crew's ability to detect insidious failures and to respond to these anomalies.
- To measure crew performance and to collect perception data when the crew must revert to basic position awareness data in the presence of a navigation or guidance failure.

4. Simulation hardware and software

4.1 General description of the Research Flight Simulator

The Research Flight Simulator (RFS) has been equipped with a transport-type cockpit, providing accommodation for a 2-man crew and an observer. On top of the cockpit two colour TV monitors for the visual display system have been installed. The dual visual system consists of a television model board with collimating system. Visibility effects such as flying in clouds, haze and fog are introduced by electronically altering the terrain image. The cockpit was mounted on a four-degrees-of-freedom motion system.

4.2 Cockpit avionics and instrumentation

Figure 1 shows the present flight deck of the RFS with the arrangement of flight instruments and controls. The left instrument panel (captain's station) had been equipped with two EFIS displays:

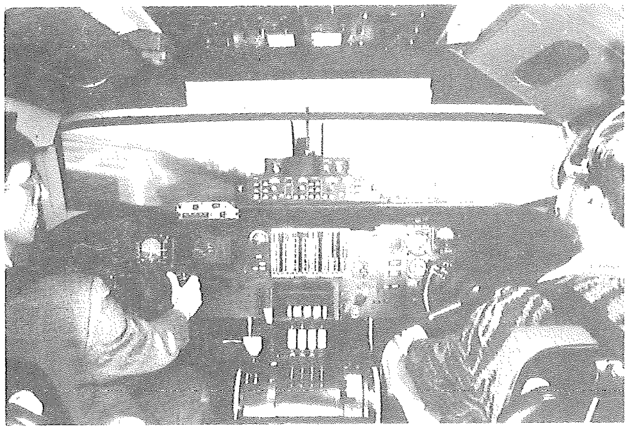


Fig. 1 View of the flight simulator cockpit.

- a standard Collins EFIS (5"x6"), which was used for primary flight display (PFD). Because this EFIS is a hardware unit from a Fokker 100 aircraft, which was made available by Fokker Aircraft B.V., the PFD format is identical to that of a Fokker 100 aircraft (see figure 2).

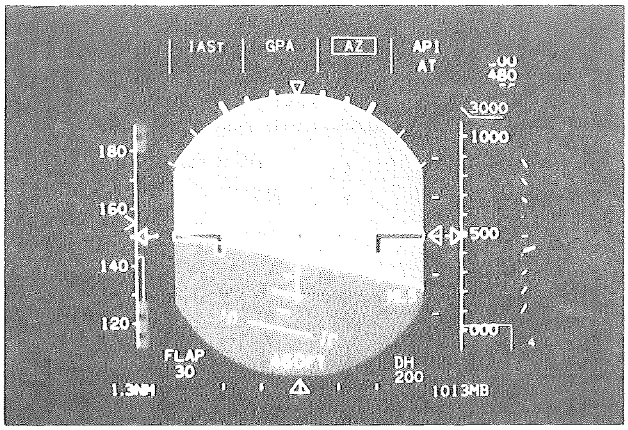


Fig. 2 EFIS primary Flight Display (Fokker 100 format)

- an emulated EFIS Navigation Display (ND), consisting of a high-resolution graphics display. The ND display formats were generated by a Silicon Graphics IRIS 3020 graphics workstation. Dependent on the selected mode, either an HSI or a MAP format was displayed. The MAP mode format (see figure 3) provided a picture of the curved path and additional pilot awareness information required for flying the curved path procedures, as recommended by RTCA[19].

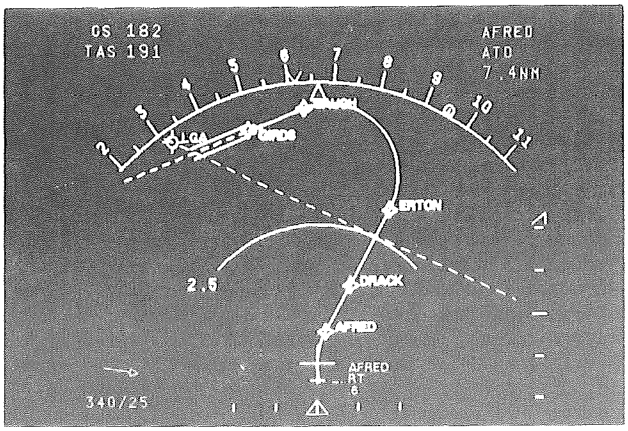


Fig. 3 Navigation Display showing the MAP mode during the ALLBE approach

---

[†] Until 1989 these investigations were carried out under contract with the Netherlands Department of Civil Aviation (RLD)

The right instrument panel (first officer's station) had been equipped with conventional electro-mechanical ADI and HSI instruments. Standard clock-type instruments were used for the various indicators like ASI, VSI and altimeter. Moreover, both instrument panels had been equipped with an RMI and several digital indicators to provide the required additional position awareness information.
An important feature for these tests was the presence of an α-numerical display, which was used as an emulated CDU display to display waypoint data. The HSI operated in the so-called "slewed" mode, which means that for the curved part of the flight path the course pointer rotates in such a way that it indicates the reference course as the tangent to the arc segment for the current position. During a turn the course bar indicates the deviation from the circular arc segment.

4.3 Simulated MLS/RNAV

The left hand side of the diagram in figure 4 shows how the MLS signals were simulated. The ICAO MLS signal model was used to generate noise on the azimuth, elevation and distance (DME/P) signals. This model has been developed especially for use as the MLS guidance signal input to flight simulators to support simulation activities associated with control system equipment.

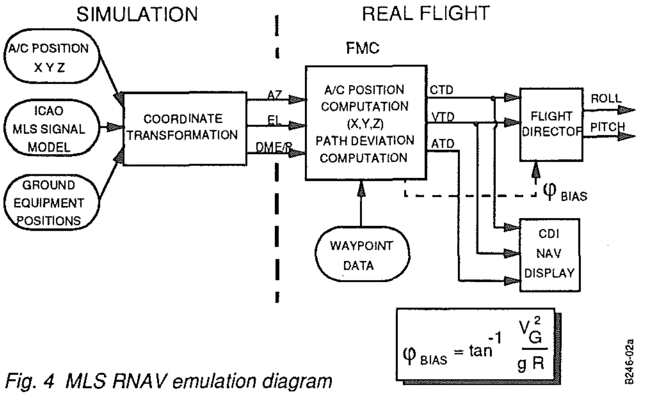


Fig. 4 MLS RNAV emulation diagram

The right hand side shows in a generic way how the RNAV system was simulated. With the three MLS signals, shown in the centre of the diagram, the actual position of the aircraft is computed in x, y, z-coordinates. Using the approach path geometry -defined by waypoint data- and the computed aircraft position data, the relative position, in terms of Along Track Distance (ATD), Cross Track Deviation (CTD) and Vertical Track Deviation (VTD), can be computed. These CTD en VTD quantities are reduced, using ATD, to similar signals as the usual localizer and glide slope signals.
This process is performed in the flight management computer (FMC). The signals obtained are used to steer the localizer and glide slope pointers on the CDI and Navigation Display. Moreover, these signals are fed into the flight director and autopilot as localizer and glide slope signals. In order to compensate for the curved flight path, during turns an additional bias signal is added to the existing tracking signals for lateral path control of flight director and autopilot. Note that for a fixed turn radius this bias signal is only a function of ground speed.

5. Approach scenarios

5.1 Description

The four curved approach paths evaluated in this program have been proposed by ATC-specialists. The procedures concern scenarios which are beneficial from an air traffic control point of view.
The selected approaches are:

- The MIKES approach, which is an MLS alternative for the present visual Canarsie arrival at JFK runway 13R.
- The PETEZ approach, which is the MLS equivalent for the present visual Hudson River North Bound approach on La Guardia runway 13.
- The ALLBE approach, which is the MLS equivalent for the present-day Expressway visual approach to La Guardia runway 31.
- The SIDES approach, which may find a future application at Amsterdam Int'l airport in the Netherlands, but has also promising potential for application to various other airports. This sidestep type approach path includes two (90°) consecutive turns.

A survey of the typical approach path geometries and the simulated visual conditions is shown in table 1, while in figure 5 the corresponding approach plates have been depicted.

Approach path	Nr. of turns	turn radius	final segment	distance FAP→TIP	cloudbase vis	DH
	--	NM	NM	NM	ft/mile	ft
MIKES	1	1.2	1.5	1.4	400/1¼	200
PETEZ	1	1.9	3.4	1.5	600/1½	200
ALLBE	2	1.3	1.1	1.5	400/1¼	200
SIDES	2	1.5	2.0	1.0	250/½	200

Table 1: Survey of approach path geometry and visual conditions

5.2 Summary of test results

Examples of test results of two curved approach paths are shown in figure 6. Results have been presented of tracking data for the MIKES (fig. 6a) and the PETEZ (fig. 6b) approaches.
From the test results on tracking accuracy it is obvious that the PETEZ approach, with the larger turn radius and the longer final segment, can be flown with much higher precision than the MIKES approach. Already from a comparison of the x-y plots one can see the substantial difference in tracking accuracy between the two approach paths. The differences are most pronounced during the turn and on the straight final segment. A comparison of the CTD-plots shows these differences more explicitly. For the purpose of reference, lines of 2-dots deviation have been indicated in the plots. These differences in accuracy also show up in the VTD-plots. In case of the MIKES approach some pilots stated that they deliberately ignored the flight director cues during the turn, if bank angles of more than 20 degrees were commanded. The plots for these flights can be clearly distinguished from the other plots.
The histograms of maximum bank angles show that for the MIKES approach the level of maximum bank

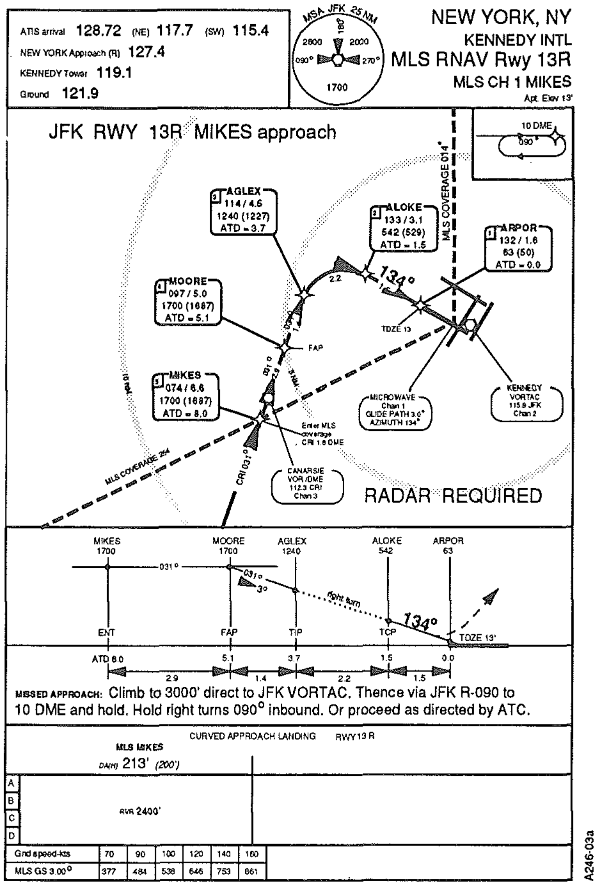


Fig. 5a MIKES approach chart

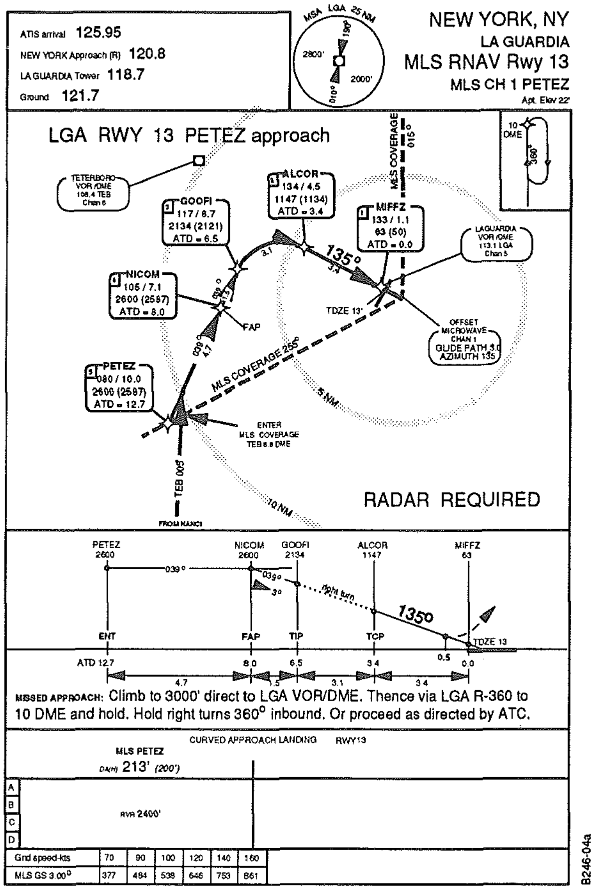


Fig. 5b PETEZ approach chart

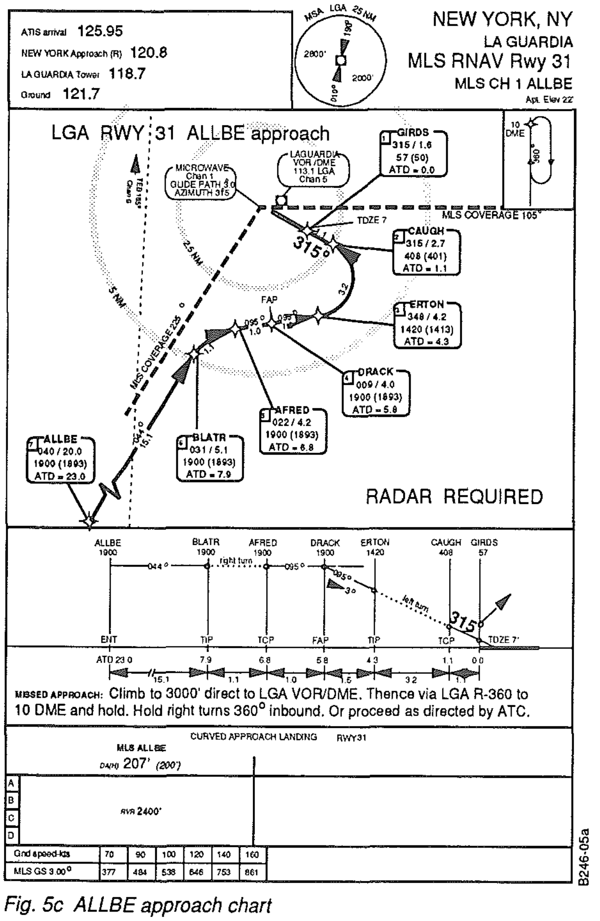


Fig. 5c ALLBE approach chart

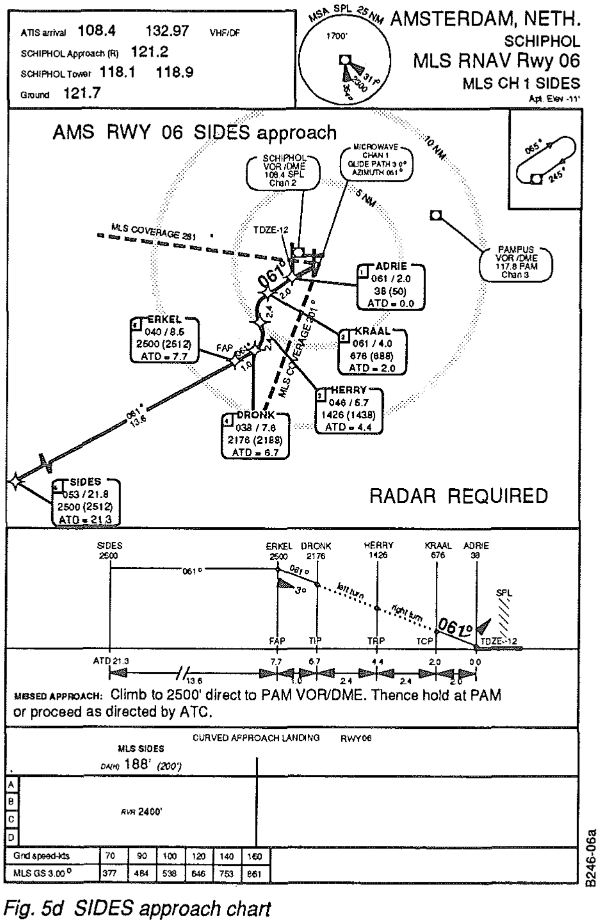


Fig. 5d SIDES approach chart

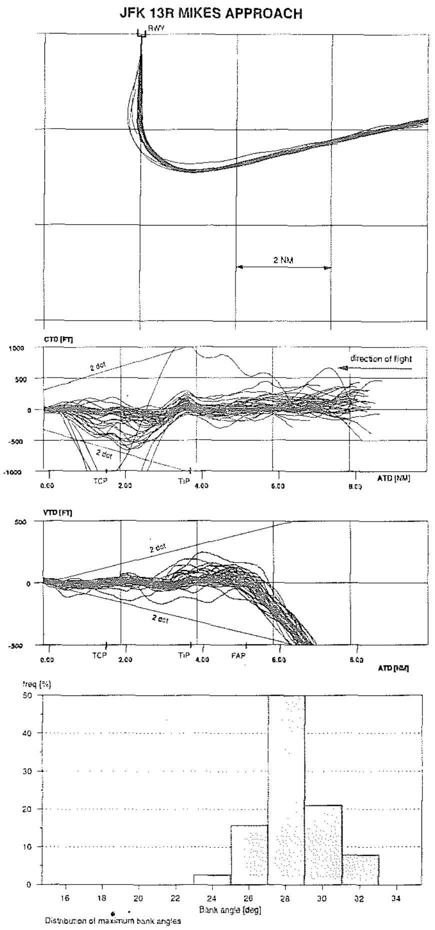


Fig. 6a Test results of the MIKES approach

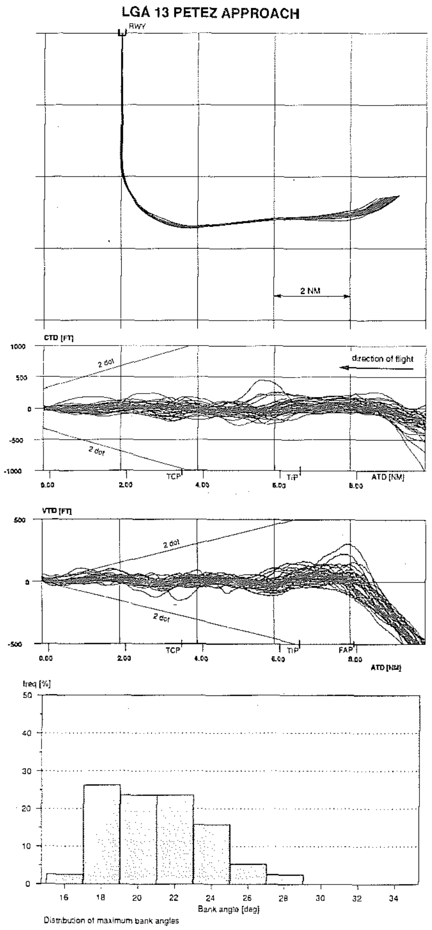


Fig. 6b Test results of the PETEZ approach

angles is substantially higher than for the PETEZ approach. A further analysis indicated that this is mainly due to the difference in magnitude of turn radius (1.2 NM versus 1.9 NM). Similar test results were obtained for the ALLBE and SIDES approaches. The turn radius and final segment of the ALLBE approach were rather short compared to the dimensions of the SIDES approach.

Approaches	Average bank angle (deg)	Maximum bank angle (deg)
MIKES	18 - 20	26 - 30
PETEZ	12	18 - 24
ALLBE	14 - 16	22 - 30
SIDES	12 - 14	18 - 22

Table 2: Comparison of bank angle resu

Table 2 presents a survey of bank angle data for the four curved approaches. As can be observed from these results the turns in the PETEZ and SIDES approaches require lower bank angles than the turns in the MIKES and ALLBE approaches.
As follows from the relation:

$$\tan \varphi = \frac{V_G^2}{gR}$$

bank angle is a function of turn radius and ground speed(V_G^2) and hence dependent on windspeed and direction. From the results of all four curved approach paths it became clear that actually not only is the final segment length critical, but also the turn radius is a very important factor for tracking performance.
It appeared that there is a strong relationship between tracking performance and pilot acceptance of the procedures:

- Firstly, a short turn radius yields high bank angles on the curved segment. This can quickly result in pilots electing to abandon precise curved segment tracking in deference of a "personal" bank limit, or in severe cases: a flight director bank limit.
- Secondly, apart from the poor tracking performance along the curved segment, too small a turn radius also leads to poor tracking results on the straight final segment, because of the resulting initial offset at the beginning of straight final.

Due to these factors the pilot's opinion on acceptance of the procedure is influenced.
A performance problem has been observed concerning lack of aggressive flight path tracking while flying the turn to the final segment. When the aircraft is still in the turn to final and clearly not on the extended runway centerline, approach path tracking seems to loose some of its urgency. It was observed that many pilots do not consider the turn a part of the precision approach. This is obviously a training issue.
The response score for "yes" to the question: "Given the conditions you just flew, did you consider this approach operationally acceptable

as a future MLS procedure?" was rather high for all four approaches. The score varied between 80% (MIKES) to 100% (PETEZ).
Although several pilots were not satisfied in case of the ALLBE approach, with the combination of short final length (1.1 NM) and associated weather minima (cloud base 400ft, vis 1¼ mile), yet the acceptance rate for the approach geometry regardless of the simulated weather minima was high: 85% (captains) to 95% (first officers). Recommended visual minima for this MLS approach were: cloud base 500ft - 600ft/ visibility 1½ mile, which are still appreciably lower than the current minima for the present Expressway visual approach (cloud base 1800'/vis. 3 mile).

From the crew responses and comments it was observed that frequently the pilots considered their performance good, although it appeared to be rather poor.

5.3 Conclusions and recommendations

With respect to the four approach paths evaluated the following was concluded:

- Under the simulated visual and wind conditions the PETEZ and SIDES approaches appear to be very acceptable from the viewpoint of tracking performance and pilot acceptance.
- The two consecutive turns in the SIDES approach can be flown without any problem.
- 1.0-1.5 NM separation between glide path intercept point and turn initiation point appears to be satisfactory.

Moreover, the following -more universal- conclusions were made:

- Concerning tracking accuracy and pilot acceptance, both turn radius and final segment length are critical parameters.
- Bank angles during turns should not exceed 25 degree, while average bank angles should be less than 15 degrees.
- Situation awareness is enhanced by a moving map display. Such a display may be very useful:
  - in case of complex procedures,
  - in situations where an early missed approach is made

Recommendations on curved approach path flying

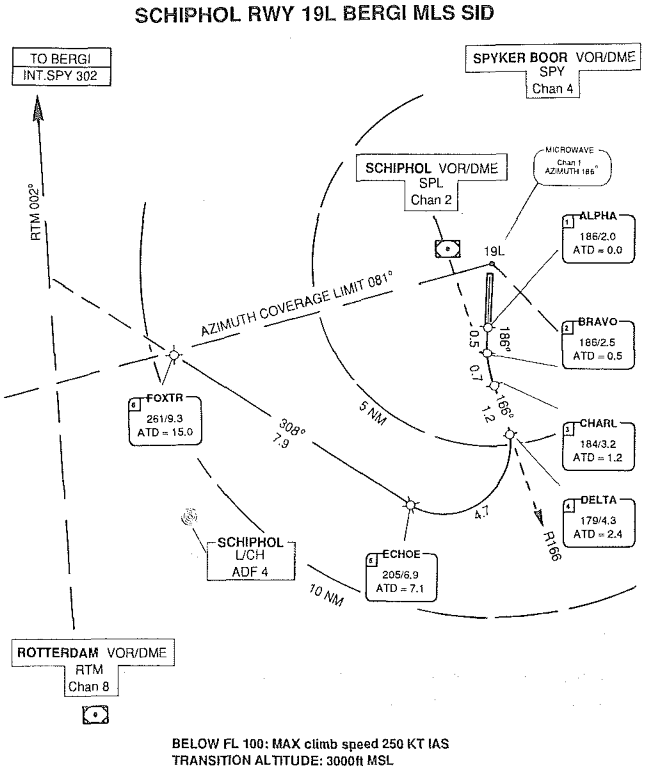
- Crews need to be trained on more aggressive flight path tracking while flying the turn to final.
- Further study is needed on the issue of crosswind during approaches with a short straight final segment. If not resolved through training, this may result in establishing a surface crosswind limitation.

6. MLS departure scenarios

6.1 Description

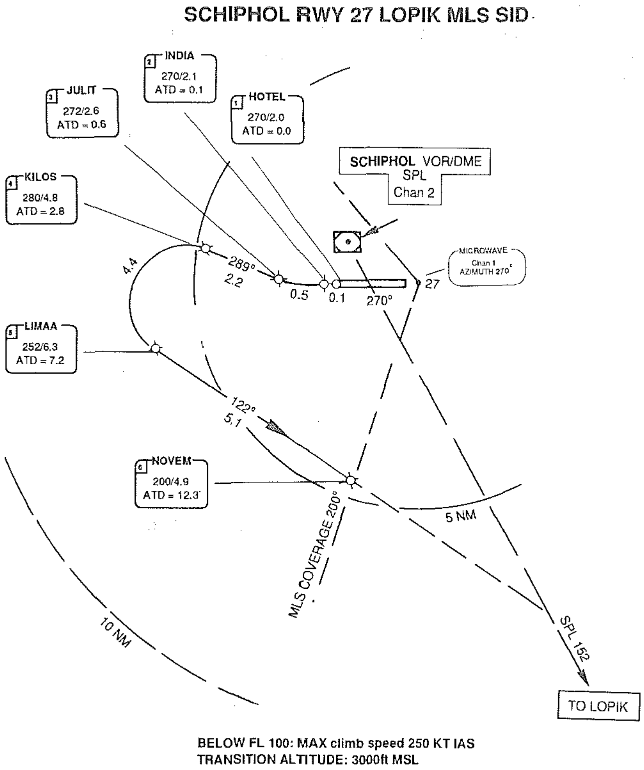
Apart from the four curved approaches, also two MLS departure scenarios have been evaluated. The departure routes for the MLS departures were based on existing SID's from Amsterdam International Airport Schiphol. The two investigated MLS departures are:
- Schiphol 19L BERGI departure
- Schiphol 27 LOPIK-departure

The departure charts for the MLS BERGI and LOPIK departures are shown in figure 7. It has to be remarked that the MLS departure routes have been designed in accordance with the existing SID



BELOW FL 100: MAX climb speed 250 KT IAS
TRANSITION ALTITUDE: 3000ft MSL

Fig. 7a MLS departure procedure AMS RWY 19L BERGI



BELOW FL 100: MAX climb speed 250 KT IAS
TRANSITION ALTITUDE: 3000ft MSL

Fig. 7b MLS departure procedure LOPIK runway 27 procedures. The waypoint labels indicate: azimuth angle, precision DME and ATD. Of course no vertical guidance is provided in case of a departure. The origin of ATD for the departures is at the departure end of the runway. Significant differences between these two departures are:

- different turn radii (BERGI:1.9 NM/LOPIK: 1.5 NM)
- different positions of the initial turning points.

Both departures were flown with a restriction on indicated airspeed during the maneuvering phase. A maximum speed of 211 kIAS (V_2 + 40) was allowed until the last turn had been completed.

During the BERGI departures the pilot-flying task was always delegated to the captains, whereas the LOPIK departures were flown by the first officers.

6.2 Summary of test results

Figure 8 shows departure tracks for the following conditions:

- BERGI departure (19 flights), flown with MLS guidance
- BERGI departure (4 flights), flown according to the current SID procedure, using the existing VOR and DME guidance. (no FMS used).
- LOPIK departure (19 flights), flown with MLS guidance.

A comparison between the tracks for the MLS-guided BERGI departure and the current BERGI SID (fig. 8a), shows that a substantial improvement in tracking accuracy can be obtained by making use of MLS guidance.

The maximum bank angles experienced during the MLS BERGI departure reached magnitudes of 28 to 34 degrees and were qualified as about right by 80% of the captains. The speed restriction applied in the turn was considered a necessity by the majority of the pilots; a maximum speed of approx. 200-210 kIAS was recommended.

The effort spent on performing these MLS-guided departures was estimated to be less than the effort spent on a visual SID, although some crews stated that it was about the same as for an FMS-flown departure.

The tracks of the LOPIK departure in figure 8b show clearly the impact of too small a turn radius in conjunction with too high an air speed on tracking accuracy. The two extremes were caused by a procedural error made by two first officers, who failed to make the proper mode selections ("level change" at 1500ft) as demanded by the checklist. Due to this omission the flight director bank angle was limited to only 15 degrees, as opposed to 27½ degrees if the proper selection would have been made. This limitation resulted in substantial track deviations. Even with these two outlier flights removed, it is clear that still very large deviations occur due to the small turn radius of 1.5 NM and the allowed speed of 211 kIAS. A second cause for the large tracking errors was the very short first straight segment, which required the initiation of a turn at very low altitude. The corresponding roll command was generally ignored by most of the pilots, who deliberately initiated the turn not before an altitude of 500 feet was reached. This introduced substantial tracking errors in the very beginning of the procedure.

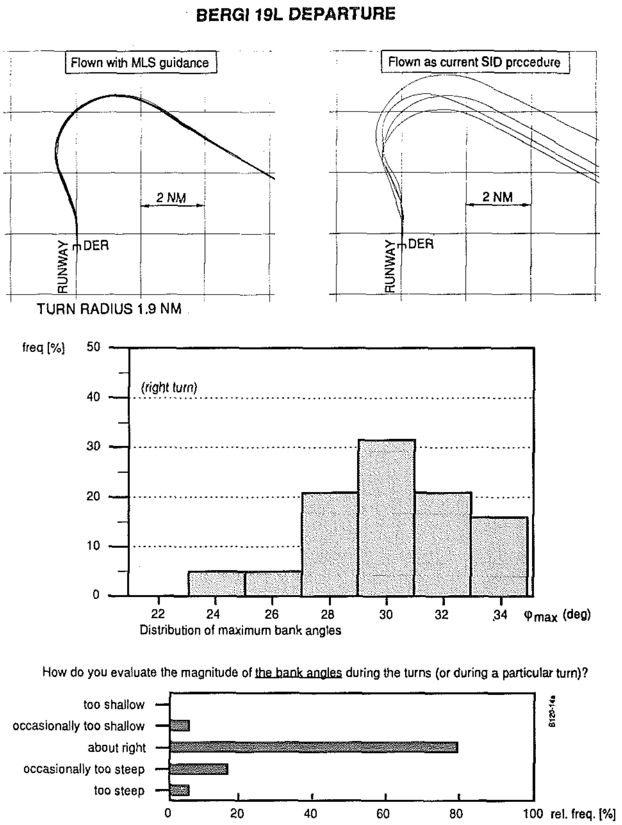


Fig. 8a Test results of the BERGI 19L departure

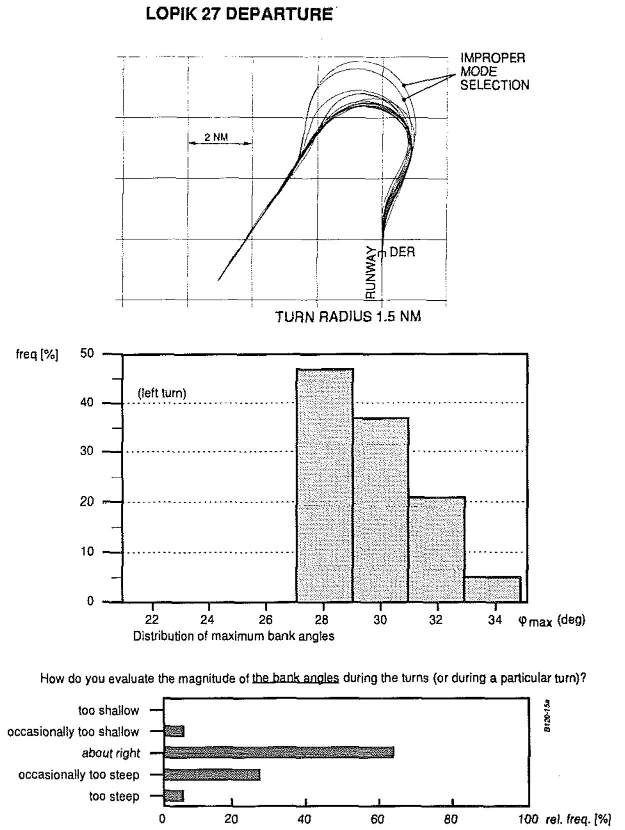


Fig. 8b Test results of the LOPIK 27 departure

The distribution of maximum bank angles (fig. 8b) does not differ substantially from the distribution in figure 8a for the BERGI departure. In both cases the maximum bank angle is around 30 degrees. However, in case of the BERGI departure the bank angles provided accurate tracking, whereas in case of the LOPIK departure accurate tracking would have required much higher bank angles. For the LOPIK departure a maximum speed of 200 kIAS or less was recommended during the turn.

6.3 Conclusions and recommendations

From the data collected from the departure tests the following conclusions and recommendations were made:

- Very precise tracking of the ground path can be obtained, provided that a speed restriction during the turns is applied. The turn radius should allow for speeds of at least V_2 + 20 kt.
- The workload for the evaluated MLS departures is lower than for the corresponding SID's.
- Turns during the initial climb phase should not require bank angles exceeding 20 degrees. After the initial climb (at approximately 1500 ft) somewhat higher values might be allowed.
- Departure procedure design should honour a sufficiently long first straight segment.

7. Example of an insidious failure

7.1 Failure description

One issue of the test objectives was to investigate the impact of equipment anomalies. For that purpose several failure scenarios had been developed. One of these insidious failures emulated an incorrect flight director roll bar steering. In this case a gradually increasing error in the flight director roll bar steering occurs shortly after passing the turn initiation point GOOFI (see figure 9). This error increases to a value corresponding to a 1 dot deviation at the end of the turn (ALCOR). From ALCOR to MIFFZ the error keeps the aircraft at a constant distance from the final approach track. It will be obvious that the CTD pointers indicate the correct deviations from the reference track. The failure could be detected by closely monitoring the deviation pointers and checking this information with the erroneous flight director commands.

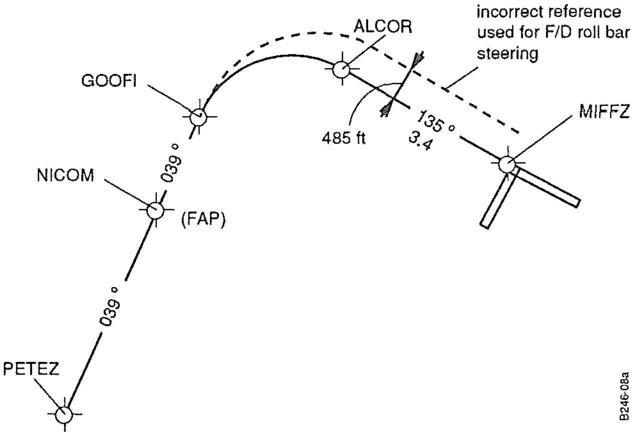


Fig. 9 Picture of the failure scenario for "divergent flight director roll bar steering

7.2 Detection of the failure and crew response

The diagram in figure 10a presents the analysis for the detection of this flight director divergency failure case, based on the results of pilot comments, and observer notes. As shown, 2 out of the 13 crews who were exposed to this scenario were not aware of any anomaly. One crew stated that they noticed that there was something wrong with the F/D at the moment of cloud break, while for two crews the anomaly was detected by the PNF only. 8 crews, of which in 4 cases the captain and in 4 cases the first officer was the pilot flying, stated that just after coming on final they discovered that the F/D was providing unreliable commands.

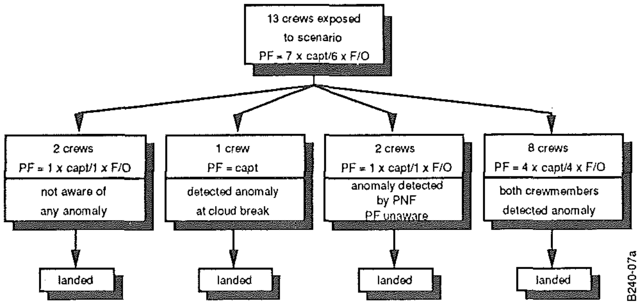


Fig. 10a Failure detection analysis for the divergency in flight director roll bar steering, based on pilot comments and observer notes.

A cross check with the recorded CTD data showed that 4 first officers and only 1 captain attempted to return to the extended runway centerline, before cloud break occurred. This indicates that the first officers had a better response to this failure than the captains, which might be attributed to be more prominent deviation cues provided by the HSI. A survey of the crew response is presented in the diagram of figure 10b.

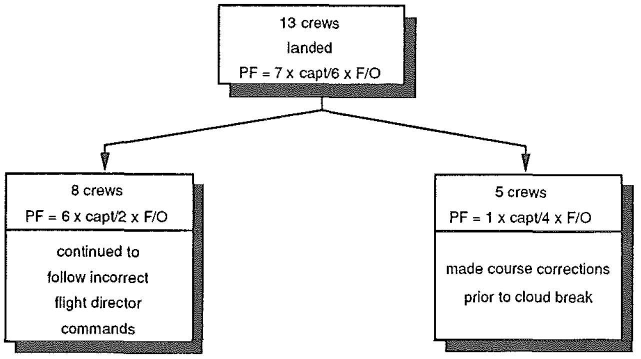


Fig. 10b Analysis of crew response to the divergency in flight director roll bar steering

The questionnaire responses indicated that 2 captains made corrective actions after they detected the anomaly. However, as stated above, the data recordings did not support these claims! These show only 1 captain returning to the extended runway centerline. Moreover, almost 50% of the pilots did fly on 2-dots deviation for a long time, yet no missed approaches were made.

Due to the fact that ultimately 8 crews continued to follow the erroneous F/D commands, it was concluded that the combination of detection and response was unacceptable.

8. RNAV failure results

In order to investigate the impact of an early missed approach on curved approach paths an RNAV computer failure was simulated. While flying the ALLBE procedure, a failure occurred on the straight segment, in between the waypoints DRACK and ERTON. The failure manifested itself to the pilots by blanking of the map display and legs page, flagging of MLS and freezing of all computed data. Only the raw data azimuth, elevation and DME/P continued to update. The failure was indicated by flags, appearing on both captain's EFIS PFD and first officer's ADI, while the ND MAP display showed the text "FMC FAILURE". This failure forced the crew to make a go-around from that position according to be prescribed missed approach procedure. It must be emphasized that also during the missed approach the navigation display was not available anymore.

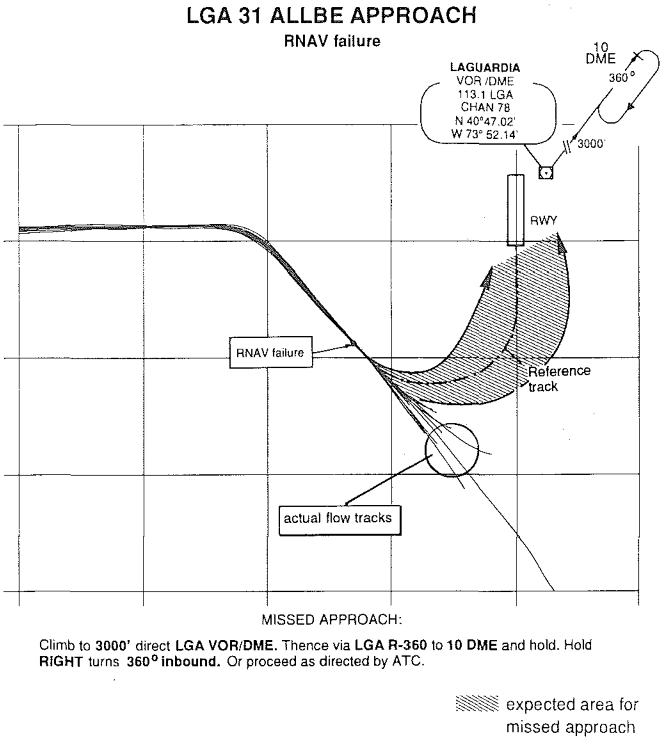


Fig. 11 Missed approach results for the RNAV failure during the ALLBE approach

The X-Y plots depicted in figure 11 show the flight tracks of the 19 early missed approaches, which were flown by the captains only. The fact that the recordings ended suddenly had to do with an unfortunate data recording convention. Nevertheless, it is obvious from the available data that these tracks are not in agreement with what one would expect. Most of the flights continued on present course for a long period of time, whereas the missed approach procedure calls for a direct left turn toward LGA VOR. From the questionnaire responses it appeared that two factors played an important role:

- firstly, pilots were not used to fly the rather complex ALLBE procedure. Additionally the missed approach was different from a normal "climb out on runway heading" procedure.
- secondly, when a anomaly occurs, leading to a missed approach, position awareness seems to suffer and desired ground track appears to be the first performance item to be abandoned.

It may be expected that the first issue can be solved by sufficient pilot training.
The second problem can be solved by stressing the importance of ground tracking during the missed approach.
Turn radius appears to be another missed approach concern. If approaches are designed for a nominal maximum bank angle at a maximum approach speed, the ability to comply with the ground track during missed approach acceleration could present a problem. If the aircraft cannot comply with the ground track, electro-mechanical instruments presents a greater problem than a map, in terms of position orientation.

Conclusions on early missed approach

- Probably due to lack of training and adequate situational awareness flight crews failed to track directly towards the missed approach beacon.
- A moving map display not only improves position awareness during a complex approach, but would also greatly enhance situation awareness during the missed approach.
- Further study has to be carried out to on situational awareness issues with respect to early missed approaches.

9. Final remark

It has to be remarked that, although the tests have been carried out using simulated MLS signals for aircraft position determination, the same results would have been obtained if use was made of a different type of sensor for position determination, provided that this particular sensor provides the same accuracy over (at least) the same coverage volume as MLS.

10. References

1. Sager, D., Simulator evaluation of manually flown curved instrument approaches. Massachusetts Institute of Technology, January 1973, FTL report R-73-1.
2. McMurtry, T.C., Gee, S.W., Barber, M.R., A flight evaluation of curved landing approaches. USAF Flight Research Centre, Edwards AFB Published by: Society of Experimental Test Pilots - Technical Review, Vol. 1, no. 3, 1973.
3. Person, L.H., Jr., Yenni, K.R., Flying NASA's Terminal Configured Vehicle against the Microwave Landing System. NASA, Langley Research Centre. Published by: Society of Experimental Test Pilot's - Technical Review, Vol. 12, no. 2, 1979.
4. Erkelens, L.J.J., A simulation investigation on the feasibility of curved approaches under MLS guidance. NLR TR 78035 U, Amsterdam, 1978.
5. Erkelens, L.J.J., Flight simulation of downwind-type approaches in an MLS environment. NLR memorandum VS-80-021 U, Amsterdam, 1980.

6. Erkelens, L.J.J., Flight simulation studies on the feasibility of laterally segmented approaches in an MLS environment. NLR MP 82025 U, Amsterdam, 1982. (Paper presented at the 13th ICAS Congress/AIAA Aircraft Systems and Technology Conference, Seattle, USA, August 1982).
7. Branstetter, J.R., Houck, J.A., Use of flight simulation to develop terminal instrument procedures for transport category aircraft. AIAA Atmospheric Flight Mechanics Conference, August 18-20, 1986, Williamsburg, Virginia, (Paper no. 86-2072).
8. Knox, Ch. E., Flying complex approach paths using the microwave landing system, SAE Technical Paper 861771, October 1986.
9. Erkelens, L.J.J., Flight simulator investigation on the approach path parameters for MLS curved approaches. NLR TR 87031 U, Amsterdam, 1987.
10. Lambregts, A.A., Development of an MLS lateral autoland system with automatic path definition. AIAA Guidance and Control Conference August 19-21, 1981. Albuquerque, New Mexico (Paper no. 81-1751).
11. Erkelens, L.J.J., Geest, P.J. van der, Hagenberg, T.H.M., Schrier, D., Pouwels, R., Investigation on MLS approach path interception and transition techniques. Part I: Fast-time computer simulations NLR TR 85097 U, Amsterdam, 1985 ICAO-COM/OPS 85, IP/23.
12. Erkelens, L.J.J., Geest, P.J. van der, Investigation on MLS approach path interception and transition techniques. Part II: Flight simulator investigation. NLR TR 85097 U, Amsterdam, 1985.
13. Erkelens, L.J.J., A flight simulator evaluation on the feasibility of advanced departure operations. NLR TR 88083 L, Amsterdam, 1988.
14. Gool, M.F.C., van, Results of MLS Procedural interception trials performed at Manchester Airport, NLR TP 89024 L, Amsterdam, 1989.
15. Hoogeboom, P.J., Results of MLS Computed Centre Line flight trials at London Gatwick Airport (April 1989) NLR CR 89335 L, Amsterdam, 1989.
16. Croll, J.B., Flight evaluation of curved MLS precision approaches in a Twin Otter aircraft (phase II). NRC NO 32149 National Research Council, Canada, Ottawa, July 1991.
17. Erkelens, L.J.J., Dronkelaar, J.H. van, Evaluation of the flyability of MLS curved approaches for wide-body aircraft. NLR TP 91396 U, Amsterdam, The Netherlands, 1991. (Paper presented at the AIAA Guidance, Navigation and Control Conference, New Orleans La, USA, August 12-14, 1991. Paper no. 91-2668).
18. Erkelens, L.J.J., Dronkelaar, J.H., van, Flight simulator evaluation of advanced MLS procedures, NLR TP 91446 L, Amsterdam, The Netherlands, 1991.
19. Anon, Minimum Operational Performance Standard for Airborne MLS Area Navigation Equipment. Radio Technical Commission for Aeronautics, Washington, D.C., RTCA Document DO-198, March 18, 1988.