**Nationaal Lucht- en Ruimtevaartlaboratorium**

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# Research on noise abatement procedures

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**ABSTRACT**
This paper focusses on the noise abatement problem around major airports. Special attention is paid to the noise regulations as applied to Amsterdam Airport Schiphol. A series of technical operational measures is subject of current NLR research. The objective of this research is to investigate how community noise, caused by arriving and departing aircraft, can be reduced without degradation of the present level of safety and without significant reduction of airport capacity during peak hours. Two noise abatement procedures, being subject of present research at NLR, are highlighted. These concern a concept for an advanced approach procedure (ACDA) and an advanced procedure for flying Standard Instrument Departures. Results of preliminary research are shown and a combined flight and ATC simulation program, to be carried out in the near future, is explained.

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# 1 Summary

This paper focusses on the noise abatement problem around major airports. Special attention is paid to the noise regulations as applied to Amsterdam Airport Schiphol. A series of technical operational measures is subject of current NLR research. The objective of this research is to investigate how community noise, caused by arriving and departing aircraft, can be reduced without degradation of the present level of safety and without significant reduction of airport capacity during peak hours. Two noise abatement procedures, being subject of present research at NLR, are highlighted. These concern a concept for an advanced approach procedure (ACDA) and an advanced procedure for flying Standard Instrument Departures.
Results of preliminary research are shown and a combined flight and ATC simulation program, to be carried out in the near future, is explained.

## Contents



(24 pages in total)

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## 2 Introduction

Many major airports are surrounded by large residential areas, which suffer from the increasing air traffic using the airport. This poses a burden on the surrounding communities by emissions produced by arriving and departing aircraft in terms of noise and of engine exhaust.
Therefore, in the terminal control area (TMA) of an airport, environmental aspects are becoming an increasingly important issue. It is expected that in the near future these aspects, rather than the amount of concrete (runways), will determine the maximum capacity of an airport.
Due to the restrictions imposed by the Dutch government on the growth of the international Amsterdam Airport Schiphol (AAS), this matter has become extremely important for this particular airport. By limiting - on a yearly basis - the cumulative noise footprint on the surrounding area, as produced by the departing and arriving aircraft, the growth of the airport is regulated.
Obviously the present departure and arrival procedures, which have been developed in an era during which only a limited range of navigation aids (ILS, NDB, VOR, DME) was available, are far from optimal with respect to an environmental point of view.
Therefore it is of paramount importance to establish, as soon as possible, new environmentally friendly procedures which have become feasible with the introduction of new approach, navigation and flight management systems, such as MLS, (D)GPS/GLONASS and modern FMS.

# 3 Situation at Amsterdam Airport Schiphol

## 3.1 General description

Figure 1 shows the geographic location and the configuration of the runway system of airport Schiphol. It has a system of four main runways and one shorter runway.
As appears from this picture, Schiphol is surrounded by several communities, ranging from the big city of Amsterdam to various small villages. Schiphol is ranked as the 4th European airport, serving yearly 24 million passengers and 840.000 tons of cargo, and is allowed to grow to 44 million passengers and 3.3 million tons of cargo.
At present a total of 6 ILS have been installed, ranging from Cat I to Cat IIIa. In order to guarantee the continuation of Cat II and III operations in the future, the decision was made to install MLS, before the year 2000, at all main runways, while maintaining ILS to the highest level of service as long as it is operationally acceptable and economically beneficial.

## 3.2 Restrictions on noise exposure

Since November 1996 noise regulations have been put into force by the Dutch Ministry of Transport, Public Works and Water Management on the arrival and departure flight operations at Schiphol. A cumulative noise contour zone, based on 35 Ke (= Dutch noise exposure index, see figure 2), has been defined for the area surrounding the airport [1]. A separate contour zone has been established for night use only. On a yearly basis cumulative noise calculations are performed, moreover actual checks are carried out by means of measurements using the Noise Measurement System Schiphol (GMS), in order to verify if the actual noise production remains within the compulsory noise contour zones.
Due to the impetuous growth of air traffic at Schiphol during the recent years, the expectations on magnitude of growth, used by the government for establishing the noise contours, are in danger of exceedance. Hence there is an urgent need for measures which reduce the noise production of departing and arriving aircraft. The space created by the measures within the noise contour zone, can be used to allow more aircraft to take-off and land.

## 3.3 Cumulative Noise exposure index

In order to express the amount of noise exposure over a period of time (e.g. one year), in the Netherlands use is made of a noise exposure index called "Kosten eenheid (Ke)". The formula for calculating the Ke index reads:

$$B = 20 \log \left( \sum_{i=1}^{N} n_i.10^{L_i/15} \right) - 157$$

in which:

B = noise exposure index (Ke)

N = total number of aircraft movements in one year.

$L_i$= maximum noise level $L_{A,max}$ {dB(A)} in a point P during the passage of aircraft i.

$n_i$= night weight factor, ranging from 1 to 10, dependent of the time of day.

Apart from this index B, which takes into account the noise over a 24 hour period of a day, a somewhat similar index, named Laeq, has been developed for the night time period only (11 PM to 6 AM).

Separate noise contour zones have been established for both indices B and Laeq.

# 4 Technical operational measures

## 4.1 Background

Apart from source measures, which -until now- mainly consisted of introducing restrictions on Chapter 2 aircraft operations and from market measures, based on differentiation of tariffs, also technical operational measures are being considered, for keeping the noise expusure within the constraints imposed by the government.

[Note: The European Member States decided already that "Chapter 2 aircraft" will not be allowed in the European airspace from April 2002]

The technical operational measures aim at reducing the aircraft noise around the airport, or more specifically:

a) to improve operational flight procedures with respect to noise abatement,
b) to optimize runway use.

With respect to the noise contour zones this means:

1) Apply maximum effort in keeping the noise production of air traffic within the established noise contour zones (35 Ke and 26 Laeq, respectively).
2) Realize a reduction of the noise exposure outside the 35 Ke and 26 Laeq zones.

Apart from these objectives, at the same time the following boundary conditions have to be satisfied:

* Safety (per individual flight) may not be adversely affected by the measures.
* Capacity during peak hours play a very important role; in principle this capacity should not reduce significantly as a result of introduction of these measures.

A series of technical operational measures is currently under consideration. In the present paper two measures related to the improvement of operational procedures will be highlighted in sections 6 and 7 respectively. One of these procedures is related to approach procedures, whereas the other concerns an advanced guidance concept for departure procedures.

# 5 Previous NLR research on advanced procedures for approach and departure

In 1977 NLR started, under contract of the Netherlands department of Civil Aviation (RLD), research on advanced procedures for approach and departure [2]. The reason for the latter research was the upcoming of the Microwave Landing System (MLS), which was advertised by ICAO and FAA as becoming the successor of the current ILS.

The larger signal coverage volume of MLS offers the potential of flying non straight-in approaches such as, for example, curved approaches. In 1989 the Federal Aviation Administration FAA became interested in NLR's work on curved approaches and other possible applications of MLS, which led to a several years lasting cooperation agreement between the FAA and NLR on the development of new flight procedures. Within this cooperation a series of investigations on NLR's Research Flight Simulator were carried out [3],[4], during which critical parameters for curved approach geometry were established, taking into account effects of wind, turbulence and visibility conditions (down to Cat II).

Also attention was paid to a new way of providing guidance along departure routes.

These new procedures have to solve problems related to:

- airspace restrictions,
- obstacle avoidance,
- noise abatement, in areas where densely populated areas are overflown by current approach and departure routes.

The results of NLR's research for the FAA have been used as input for RTCA Special Committee SC-171, in preparing the Minimum Operational Performance Standards for airborne MLS area navigation equipment (RTCA Do 198)[5]. The author of this paper was a member of the SC-171 committee at the time.

Although these procedures were all developed originating from the understanding that the guidance signals were provided by MLS, it will be evident that any other system, e.g. a satellite based system like (D)GPS and/or GLONASS, could perform this task as well, provided that the requirements for signal accuracy, signal integrity and availability are satisfied.

# 6 Research on noise abatement approaches

## 6.1 Current experiment with Continuous Descent Approaches (CDA) at Schiphol

Present approach procedures include horizontal flight segments during which the aircraft is manoeuvred -at low altitude (eg. 2000 ft)- onto the extended centreline of a runway. During this flight phase the aircraft is in a configuration which requires high thrust settings of the engines, thus producing a considerable amount of community noise and pollution.

Since last year, at Schiphol, a new approach procedure is being investigated with the objective to reduce noise of approaching aircraft. This procedure is called: "Continuous Descent Approach (CDA)". An outline of this approach procedure is shown in figure 3. The aircraft arrives from one of the three Initial Approach Fixes (IAF): ARTIP, SUGOL or RIVER at Flight Level 70 for an approach to runway 06. The CDA starts for each of the three arrival directions at a distance of 27 nm from the runway threshold at AMEGA, NORBI or DETSI, respectively. When cleared for the CDA the pilot starts his descent from FL 70 in such a way, that the ILS intercept point at 2500 ft is reached with idle or near idle power setting. As can be read from the approach plate, the procedure clearly states that the way the descent path is carried out is up to the pilot. Moreover, the procedure is allowed for RNAV as well as for non-RNAV equipped aircraft.

Preliminary results indicate that indeed the procedure reduces the noise exposure on the ground. However, in order to guarantee sufficient spacing on final, the landing interval has to be increased dramatically (from 1.8 to 4 minutes!).

From the lateral and vertical track recordings of a series of actually flown AMEGA CDA's (see fig. 4) it appears that there is a large spread between the individual tracks, especially in the vertical plane, before the ILS glide path is intercepted. The explanation for this phenomenon is that there is no unique approach path defined until the aircraft arrives at the ILS localizer/glide path. The way the approach is actually flown differs per type of aircraft and depends on the onboard equipment installed (type of RNAV), weight and wind conditions. In particular this is true for the transitions at waypoints. Due to these problems with uncertainties in the approach path to be followed, also the predictability of the approach time is inaccurate. Therefore an increased landing interval of 4 minutes is applied, which restricts the use of CDA's to night hours only, when traffic densities are very low.

## 6.2 The Advanced Continuous Descent Approach (ACDA) concept

As explained in section 6.1. the present CDA's suffer from lack of sufficient predictability of the approach path.

In order to improve the current CDA, NLR started a research project on a new concept named: "Advanced Continuous Descent Approach (ACDA)".

ACDA allows the aircraft, after passing the Initial Approach Fix (IAF), to start a continuous descent to the runway threshold along an, earth referenced, curved approach path with both lateral and vertical guidance (see fig. 5).

The curved approach path, as applied in the ACDA concept, consists of straight and circular segments.
A constant glide path angle (normally 3°) is maintained along the entire path, including the turns. The position of the aircraft is defined by three parameters (see fig. 6):
- Along Track Distance (ATD), being the distance from the aircraft to the runway threshold, measured along the predefined path
- Cross Track Deviation (CTD)
- Vertical Track Deviation (VTD)

ATD provides flight progress information along the approach similar to DME. The linear CTD and VTD quantities are reduced to signals similar to the usual ILS localizer and glide slope deviations signals.
In order to fly the circular turn segments correctly, during turns a bias signal is added to the roll channel of the autopilot and/or flight director (roll bar steering). Moreover, lead-in distances are applied at the turn initiation and turn completion points (TIP & TCP).
The formula for the bank angle bias signal reads:

$$\varphi_{bias} = \tan^{-1}\frac{V_G^{\,2}}{gR}$$

in which:

$V_G$ = ground speed
R = turn radius
g = acceleration due to gravity

During the greater part of the approach the aircraft is kept in a clean configuration, while the engines operate in a flight idle condition. Flap and gear extension are delayed. Based on distance-to-go, wind and airspeed information the FMS "ACDA mode" determines the moment at which deployment of flaps has to start and how the flap/speed schedule has to be completed. In this way stabilization in the final approach configuration at a safe minimum altitude is guaranteed.
This concept eliminates the difficulties with approach path predictability, inherent to the present CDA. Moreover it offers the possibility to fly the approach as a 4-D procedure, using wind information at altitude and on the ground as input data for the flight management computations of the ACDA mode.

### 6.2.1 Potential environmental and economical benefits of ACDA

Compared to the present-day approach procedures the environmental and economic benefits of the ACDA procedure are:

* substantial reduction of community noise (smaller "noise footprint") as a result of (see fig.7):
  a) higher altitude during larger part of the approach,

b) lower power settings / clean aircraft configuration
c) more flexibility in definition of (lateral) approach path geometry, due to curved approach application. This enables the procedure designer to design approach paths away from residential areas. Moreover, it has the additional advantage of reducing "the third party risk" (safety issue).

* less emission, due to application of "flight idle" thrust settings

* fuel conservation: less fuel is consumed during this procedure as compared to the conventional approach procedure

* reduction of the overall approach time.

### 6.2.2 Current NLR research program

Results from a preliminary paper study, carried out for two different types of aircraft (Boeing 747 and Fokker 100), indicate that the benefits which can be achieved in the area of noise reduction are substantial, whereas for the other environmental issues significant improvements appear to be feasible too.
Some results of this study are presented in figure 8a and 8b, showing the comparison between a conventional and an ACDA approach for a Boeing 747-300. In figure 8a a comparison is made for the altitude profile and engine rpm.
The ACDA results show that idle power settings are maintained all the way down until the gear is extended, whereas in the conventional approach power has to be increased in a much earlier phase of the approach.
A comparison of the resulting noise footprints (fig. 8b) clearly shows the benefits in noise abatement for the ACDA.
Because of these promising results a simulation investigation is now in preparation at NLR, under contract of the Netherlands Agency for Aerospace Programs (NIVR) to investigate the operational feasibility of the procedure and to identify the expected benefits in more detail and under highly realistic conditions. Within this scope it was decided to carry out the investigation using a coupled set-up of the NLR Research Flight Simulator (RFS) and the NLR ATC Research Simulator (NARSIM).
The purpose of the experiment is firstly to verify the expected environmental and economic benefits under realistic conditions and secondly to determine what the operational possibilities and limitations are from the viewpoints of both aircrew and air traffic controllers.
Attention will be paid to provisions needed in avionics systems, e.g. adaptations to the FMS (ACDA mode) and display systems, as well as to developments of planning and monitoring tools for supporting the air traffic controller in his metering and spacing task of handling the mix of conventional and ACDA traffic.

At the same time this simulation set-up offers the possibility of evaluating the impact of further noise reduction measures on flight technical and ATC related issues, such as:

- increasing the altitude where the approach descent is initiated,
- application of a slightly increased glide path angle (e.g. 3½°) or using a two-segment approach path,
- application of reduced (final) flap setting.

# 7 Closed-loop guided departures

## 7.1 General

The way in which Standard Instrument Departures (SID's) are implemented by the RNAV system makes accurate flying of a SID route almost impossible. This is particularly true for the turns in the SID's.

Generally a SID is defined by fly-by and fly-over waypoints, determined by ground based navigation systems like VOR, DME and NDB. Originating from the waypoint data, the FMS constructs a departure track. Figure 9 shows a series of departure tracks, as recorded by FANOMOS (Flight track and Aircraft NOise MOnitoring System). All tracks concern actual flown departures by different Boeing 747 aircraft from the same runway. As can be observed from this picture, there is a significant spread among the individual tracks.

Even under certain combinations of SID route structure and wind condition, the track that is constructed by the FMS can sometimes deviate substantially from the intended - and by the pilot expected - SID route. It will be obvious that this is an undesired situation, both from the viewpoint of safety and noise abatement.

The use of satellite navigation systems for closed-loop SID guidance provides maximum flexibility as far as route definition is concerned. Therefore, the departure route geometry can be adapted to the local situation in a way that populated areas are avoided as much as possible and existing noise abatement departures routes are made more effective because of the very accurate way the prescribed routes can be followed.

Precision flying of SID's will require tightly coupled avionics to keep the flight technical error to reasonable limits. Using the closed-loop guidance concept this can be achieved.

## 7.2 Closed-loop SID concept

In case of a closed-loop guided SID, the route is defined by straight and circular segments, similar as in case of a curved approach path. Of course with the omission of the vertical path. The SID is now uniquely defined for all aircraft. For guidance, use can be made of a satellite navigation system signals.

A great advantage of this concept is that the accuracy by which the SID routes are flown is significantly improved compared to the present open-loop SID guidance case. Figure 10 presents a result of the flight simulator trials described in [3]. These simulation results were obtained with the Boeing 747-200 model. It appeared that for a fixed turn radius of 1.9 NM, the resulting bank angles are acceptable (see fig. 10b). The following conclusions and recommendations were obtained from this study:

- Closed-loop guided SID's enable very precise tracking of the desired ground path,
- Workload for these departures is less than for current, open-loop flown, SID procedures,

- Turns during the initial climb (to 1500ft) should not require bank angles exceeding 20 degrees,
- Departure procedure design should honour a sufficiently long first straight segment.

# 8 Research tools

## 8.1 General

For research on flight procedures NLR has at its disposal two flight simulators, viz. the Research Flight Simulator (RFS) and National Simulation Facility (NSF), as well as the NLR ATC Research simulator (NARSIM). To investigate new ATM concepts, a voice and datalink between NARSIM and both the RFS and the NLR research aircraft is available. This so-called Delta concept is illustrated in figure 11. Due to the nature of the present research topic, the initial experiments will be carried out using a coupled set-up of the RFS and NARSIM. In a later phase of the research also the involvement of research aircraft is foreseen.

## 8.2 Research Flight Simulator

NLR's research flight simulator (RFS) will be used in studies into new flight procedures.
The RFS facility consists of a set of advanced hardware and software components, structured in a modular fashion to allow virtually any vehicle to be simulated. The simulator equipment consists of many modules, such as cockpits, visual, motion and computer systems, and a large set of simulation software tools.
A picture of the interior of the cockpit is shown in figure 12. The cockpit, which can accommodate a three man crew, is a "full glass" transport cockpit, equipped with six EFIS and three CDU's (all fully programmable).
Available aircraft models for simulation are: Fokker F28, Fokker 100, Fokker 50, Boeing 747-200/300/400, Cessna Citation, Fairchild Metro II. All simulation models are written in FORTRAN-77; the language C is only used for graphical models and simulator-interfaces software. Graphics workstations (Silicon Graphics IRIS) are used for cockpit display generation and (limited) outside view generation.

## 8.3 Air Traffic Control Research Simulator

Research with NARSIM is primarily aimed at the development of advanced automated tools and the integration of ground- and air-based systems. These advanced automated tools support for example the prediction of aircraft trajectories, the prediction of conflicts between aircraft and the detection of excessive deviations from planned routes. A picture of the air traffic controller workstation is shown in figure 13. With NARSIM and RFS in a coupled configuration, the ATC process can be simulated, having both the air traffic controller and the pilot in the loop.
NARSIM also serves as a prototyping testbed for the new Amsterdam Advanced ATC system (AAA), incorporating new ATM tools such as Converging Runway Display Aid (CRDA), Area Conflict Detection (ACOD) and Short Term Conflict Alert (STCA).

## 9 Concluding remarks

Optimal utilization of the upcoming new systems for approach, navigation and flight management will lead to the introduction of more efficient flight procedures. These will contribute to:

- improvements in noise abatement,
- airport capacity enhancement,
- reduction of radarvectoring, leading to ATC workload relief,
- more efficient and safer operations in the TMA.

Before these flight procedures become available for operational application, however, a lot of research work has to be carried out. This comprises not only flight- and ATC simulations studies but also in-flight demonstrations, to prove the operational feasibility of the concept of a particular procedure under real life conditions.

Since a world wide implementation of these procedures is pursued, an international co-operation between aircraft-, engine- and avionics manufacturers, civil aviation authorities and research institutions is urgently recommended.

## 10 References

1. Frankena, P., Kommer, M.J. van den (in Dutch language): "Invoerboek geluidsbelastings-berekeningen ten behoeve van de definitieve aanwijzing luchtvaartterrein Schiphol" (*Book of input descriptions for the noise calculations concerning the final allocation airport Schiphol*), NLR CR 96645 L, Amsterdam, Nov. 1996.

2. Erkelens, L.J.J., *"A simulation investigation on the feasibility of curved approaches under MLS guidance"*. Paper presented at AGARD Modeling and Simulation of Avionics Systems and Command, Control and Communications Systems, 15-19 Oct. 1979, Paris, France. AGARD CP 268 (paper #37).

3. Erkelens, L.J.J., Dronkelaar, J.H. van, *"Evaluation of the flyability of MLS curved approaches for wide-body aircraft"*, Paper presented at the AIAA Guidance, Navigation and Control Conference, New Orleans (LA), USA, August 12-14, 1991.

4. Erkelens, L.J.J., Dronkelaar, J.H. van, *"Development of advanced approach and departure procedures"*. Paper presented at the 18th ICAS congress, 21-25 Sept. 1992, Beijng, People's Republic of China.

5. Anon., *"Minimum Operational Performance Standards for Airborne MLS Area Navigation Equipment"*. RTCA Document Do-198, Prepared by RTCA Special Committee SC-171. Washington D.C., USA.

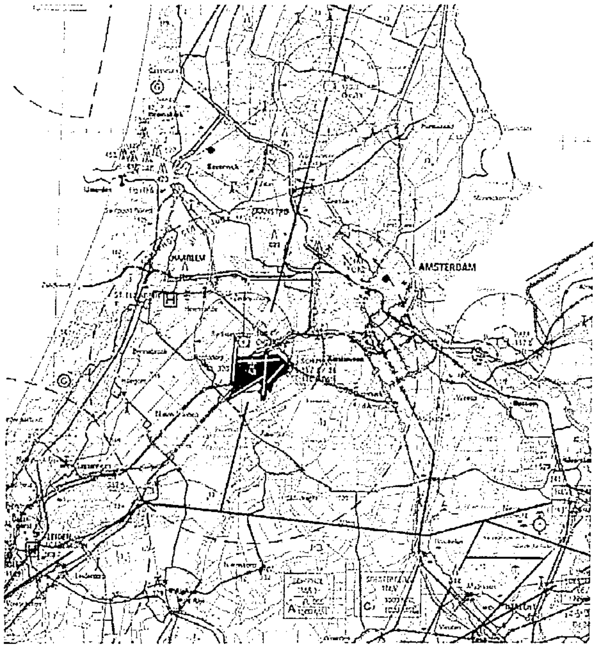


*Fig. 1 Schiphol and its surroundings*

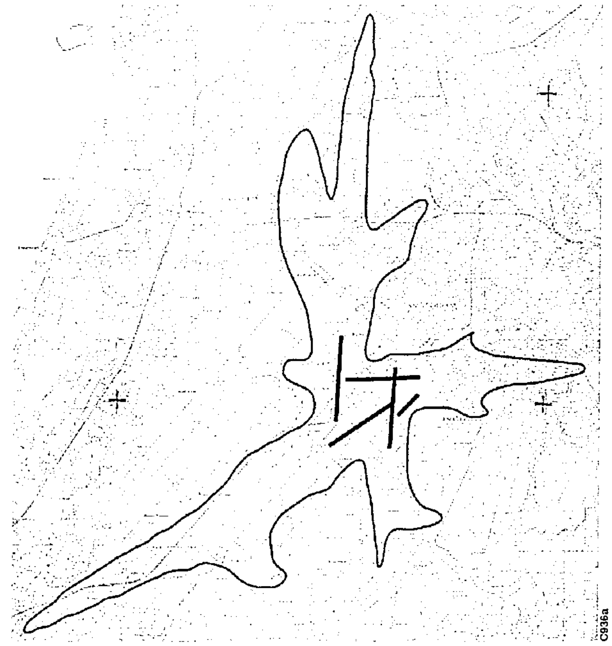


*Fig. 2 Noise contour zone around Schiphol (35 Ke)*

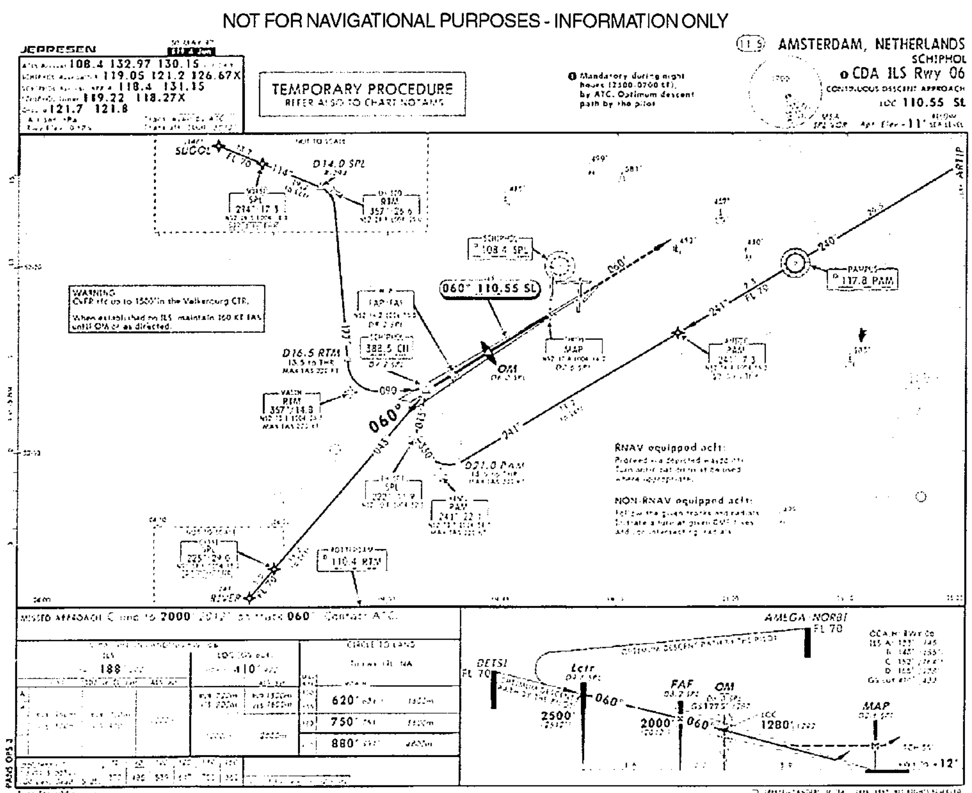


*Fig. 3 Approach plate for CDA on ILS runway 06*

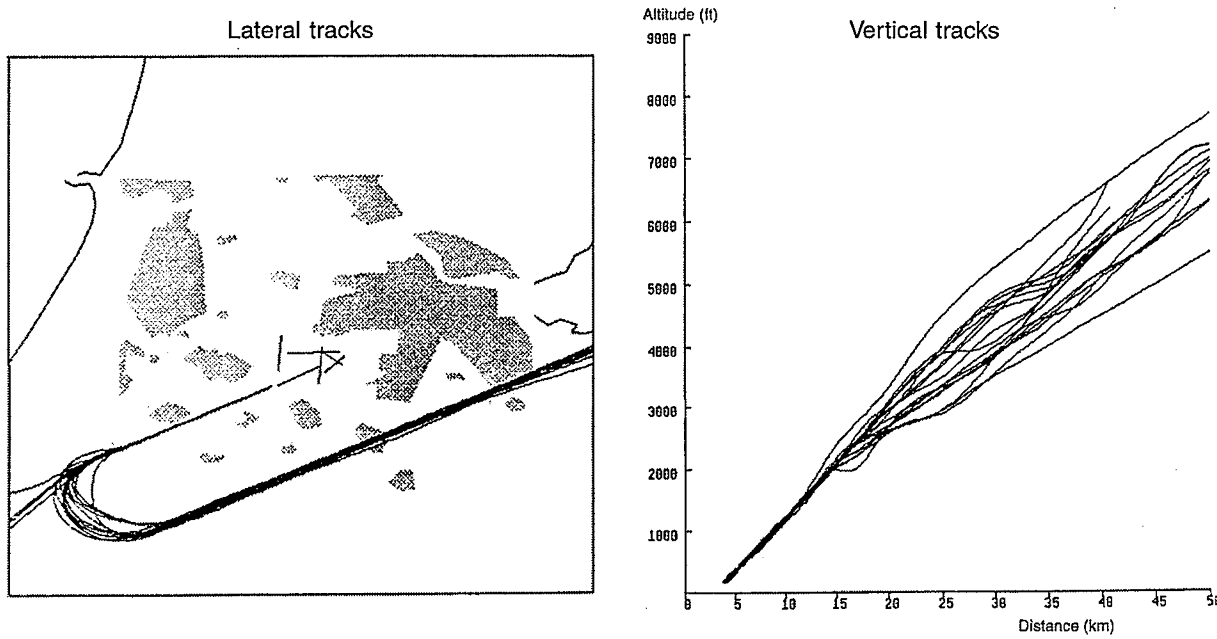


*Fig. 4 Lateral and vertical track plots for the AMEGA CDA (source: "Op de bok", aug '96)*

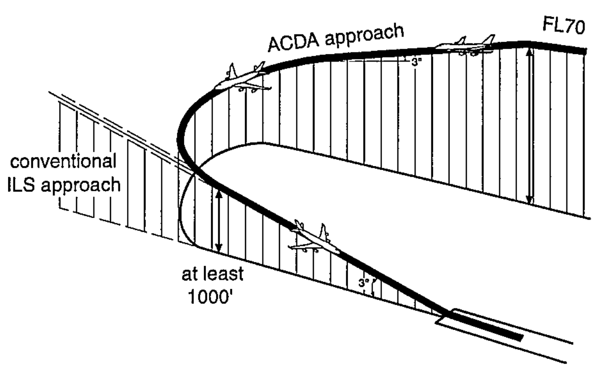


*Fig. 5 ACDA concept*

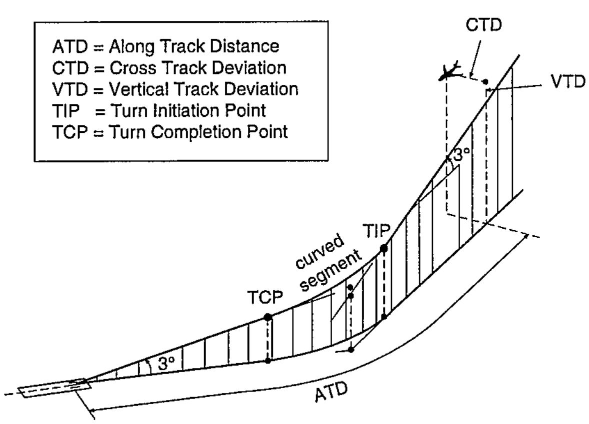


*Fig. 6 Definition of aircraft position along a curved approach path*

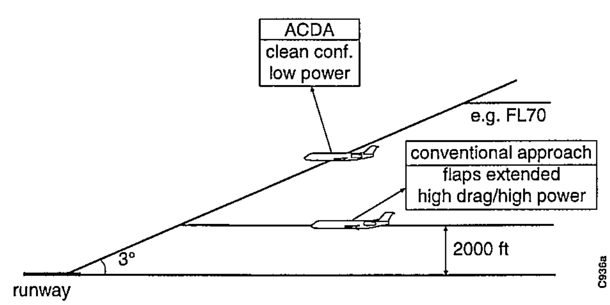


*Fig. 7 Comparison of vertical profiles for conventional approach and ACDA*

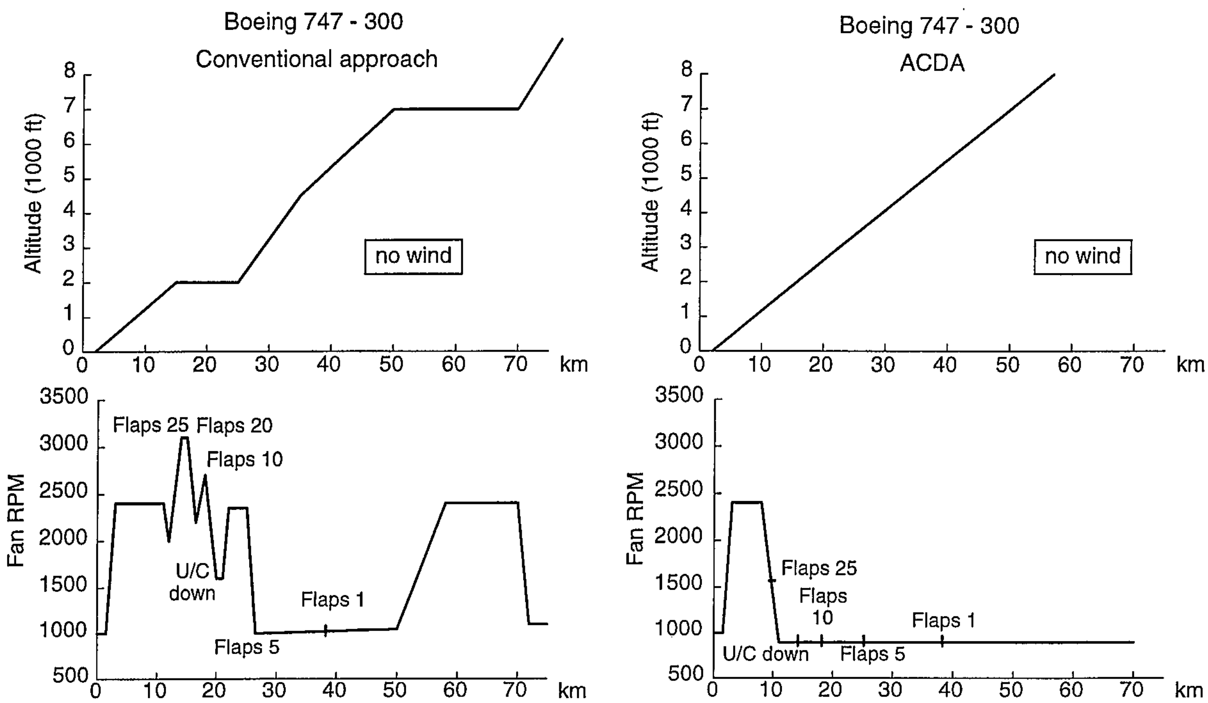


*Fig. 8a Comparison of Boeing 747 engine RPM for conventional approach and ACDA*

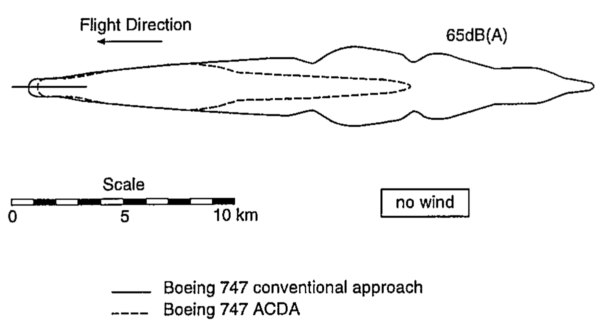


*Fig. 8b Comparison of Boeing 747 noise footprints [65 dB (A)] for conventional approach and ACDA*

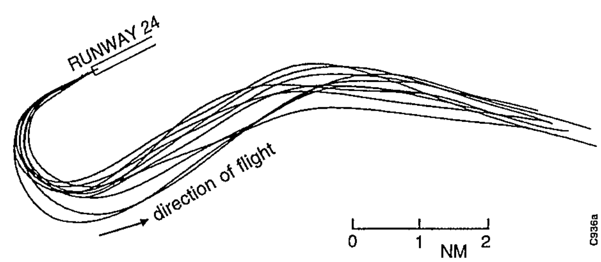


*Fig. 9 Recorded Fanomos tracks for actual Boeing 747 departures from Schiphol runway 24*

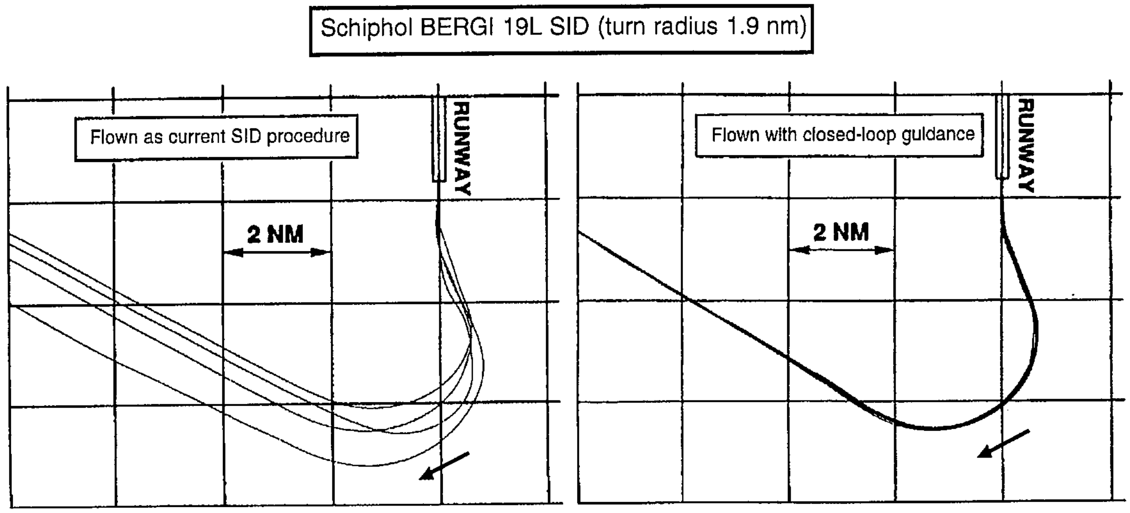


*Fig. 10a Comparison of flight simulation results between current and closed-loop guided SID's*

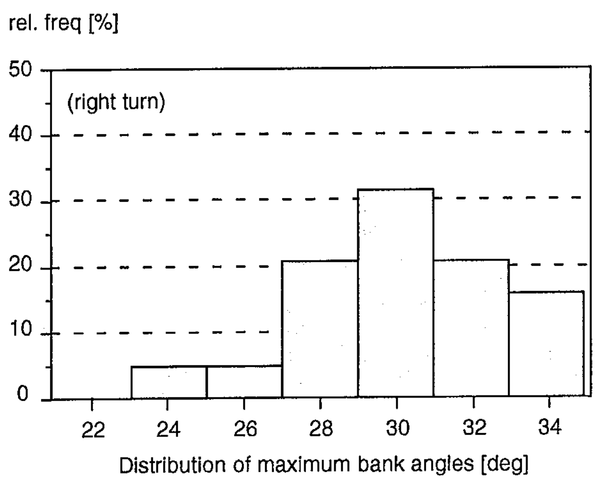


*Fig. 10b Histogram of maximum bank angles during the turn of the closed-loop BERGI SID*

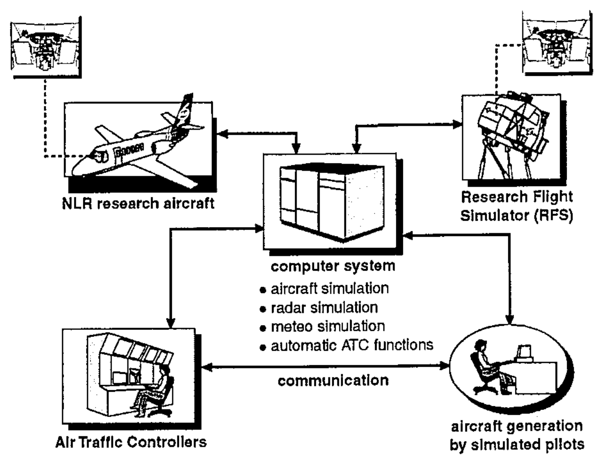


*Fig. 11 Possible communications between different NLR research facilities*

*Fig. 12 Full-glass cockpit of RFS*

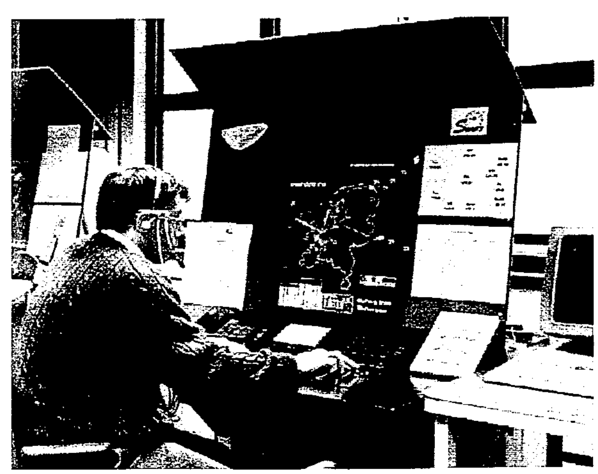

*Fig. 13 Air Traffic Controller workstation*