FROM NONPRECISION APPROACHES TO PRECISION-LIKE APPROACHES:

Methods and Operational Procedures

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Introduction

The methods and operational procedures that have been defined by airframe manufacturers, airlines and other operators for pilots to fly non-ILS (instrument landing system) approaches have evolved over the past 35 years.

The evolution of these procedures has been dictated by the following factors:

- The way nonprecision approaches (NPAs) or precision-like approaches are defined;
- The navigation sensors used aboard the airplane; and,
- The on-board instruments provided to fly the approach and monitor the approach.

The combination of these factors has enabled rationalization of the methods and procedures, from the traditional step-down approaches — also known as "dive-and-drive approaches" — to the constant descent angle/stabilized approach method.

This rationalization has significantly improved the safety level of these approaches; indeed, the latest procedures — when applicable — have suppressed the main causes of unstabilized approaches and, thus, minimized the risk of controlled flight into terrain (CFIT) during final approach.

This evolution and rationalization have been achieved schematically in three steps since 1970:

- First step, 1970s — NPAs;
- Second step, 1980s — constant descent angle/stabilized NPAs; and,
- Third step, 1990s onward — precision-like approaches.

Main Factors Involved in NPAs

Any type of instrument approach procedure (IAP) to a runway is a lateral and vertical trajectory defined so as to be flown by airplanes in instrument meteorological conditions (IMC) down to the applicable minimums, where visual references must be acquired by the pilots in order to safely continue the approach and landing.

Instrument approaches are supported by various navigation systems and may be divided into two types:

- The ILS — or, more generally, a landing system (LS) approach — provides lateral and vertical beams down to the runway, allowing precision approaches and autoland procedures; and,

- The non-ILS approaches — that is, NPAs, area navigation (RNAV) approaches and precision-like approaches — provide a lateral course or pattern supported by a radio navigation aid (navaid), with the vertical path of the approach being defined in a more-or-less discontinuous way.

With the availability of advanced navigation sensors and airborne navigation systems —including the inertial reference system (IRS), global positioning system (GPS) and flight management system (FMS) — the RNAV point-to-point method of navigation, which is not dependent on the position of ground-based navaids, has allowed more flexibility in the definition of the final approach lateral and vertical paths.

In all cases, the final approach starts at a final approach fix (FAF) and ends at the missed approach point (MAP) or at the MDA(H) (minimum descent altitude/height) or DA(H) (decision altitude/height).

Traditionally, the final segment of most instrument approaches has been straight-in. However, during the last decade, with the availability of high-performance navigation and on-board flight management and guidance systems, segmented and/or curved final approaches have been defined.

The methods and procedures provided to aircrew by manufacturers, operators and airlines to fly instrument approaches in IMC have varied over time because they depend upon two main factors: the "nature" of the approach and the on-board equipment.

The Nature of the Non-ILS Approach

Traditional NPAs in the 1970s

These approaches are referenced to a ground radio navaid used to define the final approach trajectory or pattern. Over the last 30 years these navaids typically have included the nondirectional beacon (NDB), VHF omnidirectional radio (VOR) and localizer (LOC) — often colocated with distance measuring equipment (DME).

These approaches are called *nonprecision* approaches because the overall performance of these approaches is dictated by:

- The performance of the navaid, itself. The typical accuracies of the navaids are:
  - NDB, plus/minus 5 degrees;
  - VOR, plus/minus 3 degrees;
  - LOC, plus/minus 0.2 degree; and,
  - DME, 0.2 nm or 2.5 percent of distance;
- The location of the navaid on the airfield or close to the airfield relative to the extended runway centerline. The location affects the approach pattern and the difficulty of flying the approach — and, therefore, the flight accuracy. Typical navaid locations include the following:
  - On the airfield and on the extended runway centerline, allowing a straight-in approach with no offset (Figure 1, page 3);
  - On the airfield, abeam the runway and associated with an approach pattern, such as a teardrop procedure turn (Figure 2, page 4), with an offset final segment; and,
  - Abeam the extended runway centerline, associated with a significantly offset final approach trajectory — for example, more than 30 degrees — usually due to surrounding terrain (Figure 3, page 5);
- The availability of DME as part of the reference navaid — for example, VOR/DME — or of a system providing the airplane's distance to the runway threshold — for example, an RNAV computer — significantly enhances the capability of the pilot to know the airplane's position along the lateral path of the final approach. Furthermore, the distance information allows better adherence to the intended vertical

flight path of the final approach by conducting altitude/distance checks; and,

- The nonprecision nature of the approach is also caused by poor definition of the final approach's vertical path. NPA charts typically provide only an assigned altitude at the FAF and the distance from the FAF to the MAP. Thus, crew awareness of the airplane's vertical position versus the intended vertical path of the final approach is quite low.

RNAV Approaches of the 1980s: These approaches comprise point-to-point trajectories. Each point may be defined either by a bearing/distance to a reference ground navaid such as a VOR/DME or, as is the case today, by a geographic position defined by latitude and longitude. Each point is assigned a crossing altitude.

Consequently, RNAV approaches clearly define both a lateral and a vertical trajectory that the airplane must maintain on final approach. Some RNAV approaches are published as "overlays," or supplements, to existing approaches; the geographic trajectories are the same.

Although most RNAV approaches are straight-in approaches, some comprise a succession of nonaligned straight segments and are known as segmented approaches. In order to fly segmented RNAV approaches, adequate airplane equipment is required, as set forth in the applicable approach chart (Figure 4, page 6).

RNP RNAV Approaches of the 1990s Onward: Required navigation performance (RNP) RNAV approaches are basically defined as RNAV approaches within a performance-based navigation concept.

This concept means that the airplane is able to fly the RNAV approach trajectory and to meet the specified RNP criterion — for example, RNP 0.15 nm. Thus, the airplane's navigation system has to monitor its actual navigation performance (ANP) — typically, total navigation error, including system and flight technical error —

Cairo — VOR DME Runway 23L

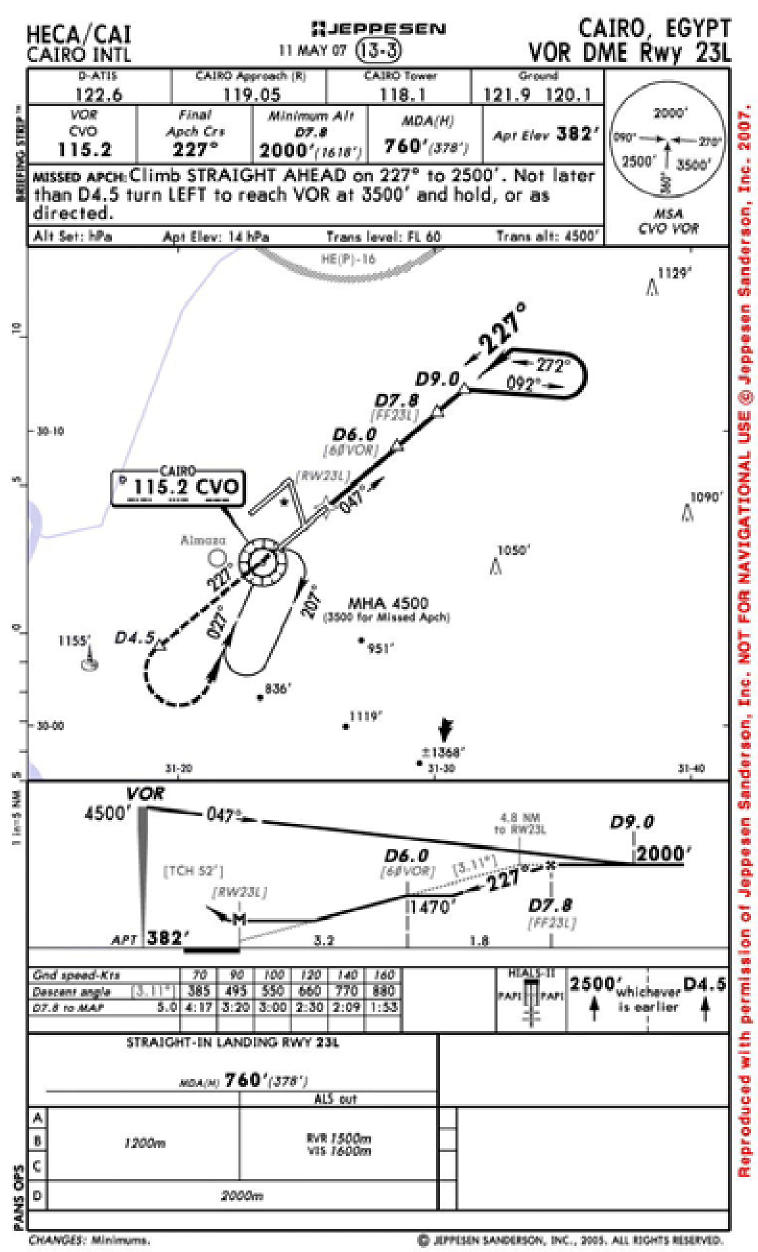

Figure 1

and has to show whether the RNP is actually being met during the approach.

The performance-based navigation concept ensures that the airplane remains "contained" within a specific volume of airspace, without requiring an outside agent to monitor its accuracy and integrity.

This concept provides great flexibility for approach designers; indeed, the notion of

Bunia — VOR Runway 10

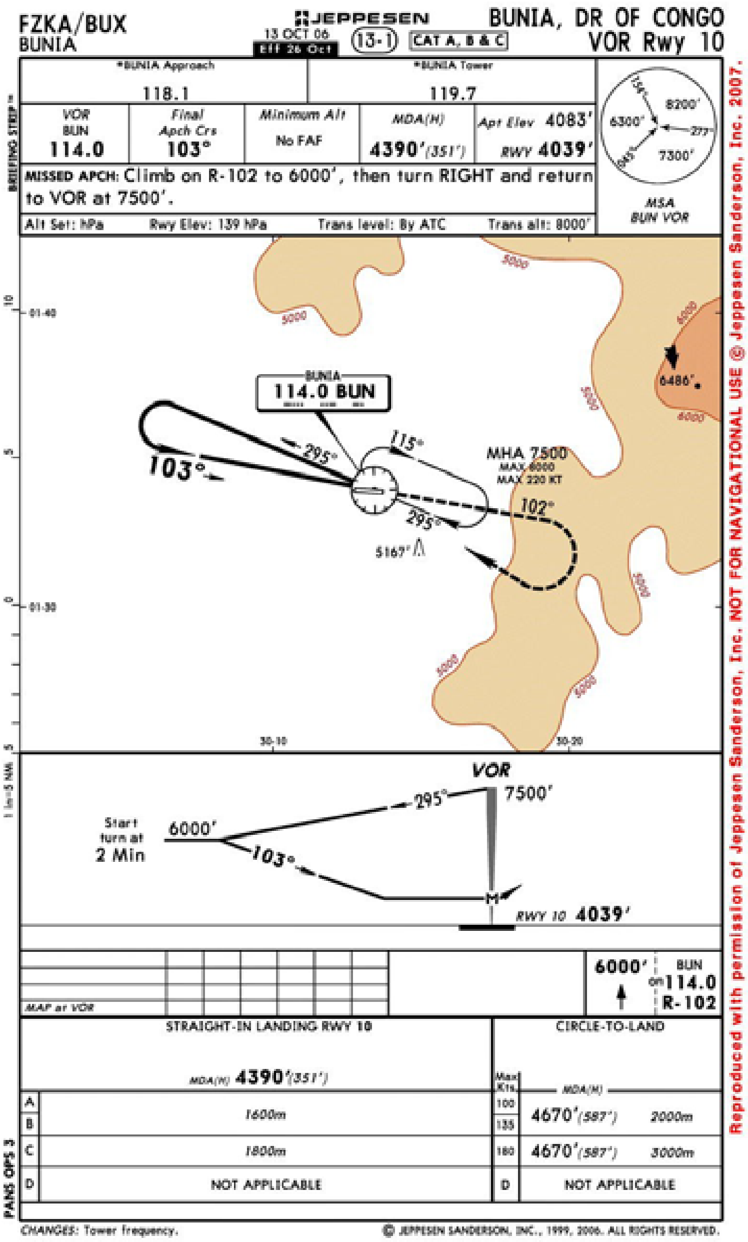

Figure 2

containment allows them to consider approach trajectories that can satisfy various potential conflicting constraints — such as terrain, noise, environment and prohibited areas — while ensuring a comfortable, flyable, constant descent angle vertical path, with approach minimums dictated by RNP, as shown by Figure 5, page 7.

RNP RNAV approaches are therefore point-to-point approaches; the various segments of the approach may be either straight or curved but are all geographically defined, as shown by Figure 6, page 8. The approach vertical path is a constant angle.

The On-board Equipment: The methods and procedures recommended to fly non-ILS approaches depend upon the ability of the on-board equipment to ensure the following functionalities:

- Navigation;
- Guidance; and,
- Display.

Navigation Functionalities: The navigation functionalities are those which provide the pilot with the system's best estimation of the airplane's position and its deviation from an intended flight path.

First step, the 1970s: Navigation functionalities were essentially based on on-board equipment that received signals from ground-based navaids such as NDBs, VORs, LOCs and DME.

Some airplanes also were equipped with an inertial navigation system (INS) that could be updated by specific navaids. For long-range flights, long-range navigation (LORAN) and Omega navaids, and RNAV computers also were used.

For non-ILS approaches, traditional ground-based navaids were the reference sources of navigation information.

Second step, the 1980s: Two major advances were made in navigation functionalities: the widespread use of IRS and the adoption of the FMS.

Most commercial airplanes were equipped with at least one IRS, which calculated the airplane's position autonomously with a good performance level, and at least one FMS, which processed the airplane's position based on data from other on-board systems, and ensured flight navigation functions.

The FMS used all IRS positions available and averaged these positions into a "MIX IRS" position, which then was updated using information from the best pair of DME stations within range or using a VOR/DME within range. Consequently, the FMS could provide a good airplane position, along with an estimate of its accuracy.

The FMS then and today provides lateral and vertical flight planning functions, which means that it can string together all the legs of a flight plan, including all the legs constituting the approach.

The FMS is able to assign crossing altitudes at various waypoints of the approach as well as a descent angle for certain legs such as the final approach leg.

As a result, the FMS processes the airplane's position and provides an estimate of its accuracy and the lateral/vertical deviations which may exist between the airplane's position and the flight plan. Figure 7, page 9 shows typical FMS progress and flight-plan pages.

Third step, the 1990s onward: The major step forward in this period is the advent of GPS, because of its remarkable accuracy, its capability to properly confirm performance, its quasi-worldwide and quasi-permanent availability, and its capability to monitor its integrity.

GPS is used as a primary navigation sensor by the FMS, which also displays navigation performance as estimated error or ANP.

The resulting FMS-computed position is very accurate, which explains the shift in terminology from "nonprecision approach" to "precision-like approach" when flying an instrument final approach using GPS as the basic navigation sensor.

The navigation databases used by the FMS have been upgraded and rationalized as follows:

- RNP values assigned to approach legs may be included in the FMS database;
- All flight plan legs are geographically defined — that is, referenced to Earth — and fixed-radius turns are provided between two legs, making these turns also geographic trajectories. The importance of defining "geographic" legs will be illustrated further when discussing the design of curved RNP RNAV approaches in a mountainous environment; and,
- Whenever required, the descent angle assigned to a leg — for example, during approach — also is included in the FMS

Le Ceiba — NDB DME Runway 07

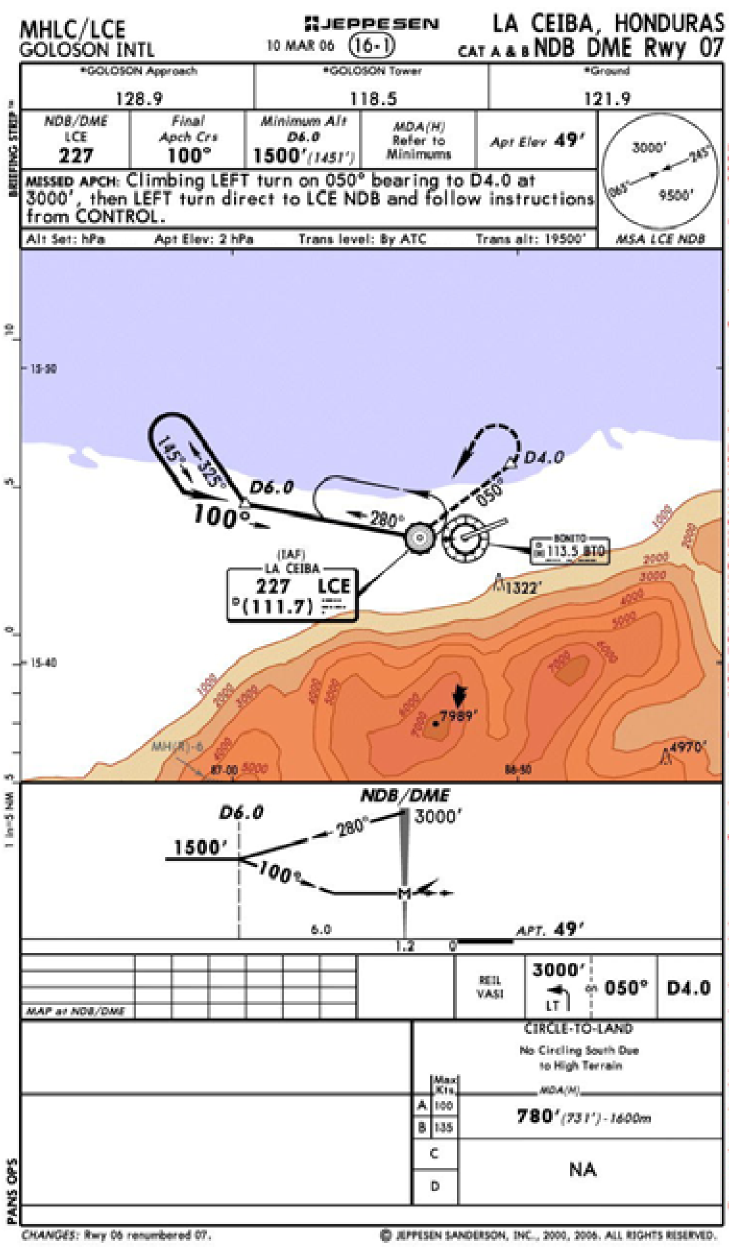

Figure 3

database, for a better determination of the approach profile.

Figure 8, page 9 shows a typical FMS progress page with "GPS primary" data and a position-monitor page.

Guidance Functionalities: The guidance functionalities are those used by the pilot to fly the airplane during approach.

Palmdale — RNAV (GPS) Runway 25

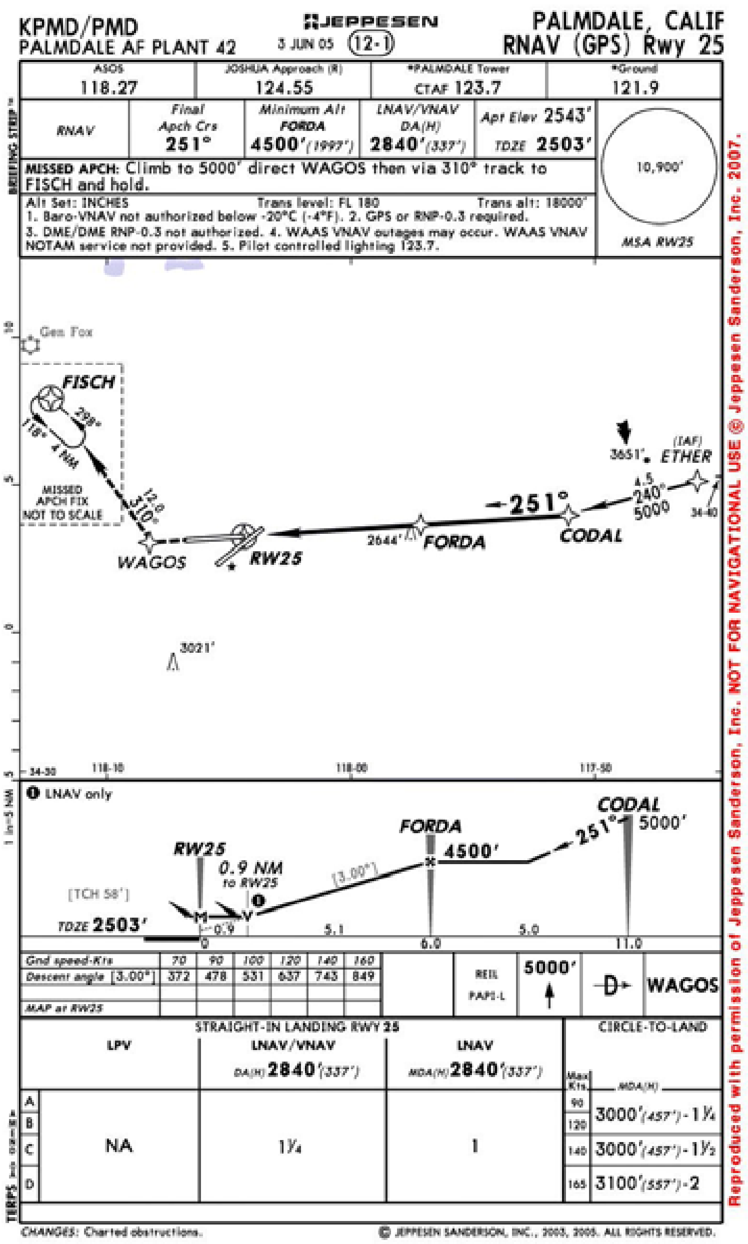

Figure 4

First step, the 1970s: In IMC, the pilot used the conventional attitude director indicator (ADI) and horizontal situation indicator (HSI) as references to fly the airplane. In order to control a descent or climb gradient, he/she used the vertical speed indicator (VSI) as well as the altimeter.

Most commercial airplanes were equipped with an autopilot (AP) and a flight director (FD) with more or less advanced modes, such as:

- Pitch;
- Vertical speed (V/S);
- Heading (HDG);
- VOR/LOC; and/or,
- Navigation (NAV), if an INS or an RNAV computer was installed.

Figure 9, page 9 shows an ADI and an HSI, as installed in an Airbus A300.

Second step, the 1980s: Two major advances were made in guidance functionalities in this period:

- The introduction of the "glass cockpit" featuring an electronic flight instrument system (EFIS) that replaced conventional ADIs with primary flight displays (PFDs) providing new flying cues such as the flight path vector (FPV). The FPV gives pilots the instantaneous flight path angle (FPA) and track (TRK) flown by the airplane, hence its instantaneous trajectory. The FPV assists the pilot in flying and controlling stabilized segments of trajectory, particularly during final approach. The FPV may be used alone or in association with the flight path director (FPD).
- The introduction of the FMS and the FPV allowed additional AP/FD modes to be adapted to tracking a trajectory. The FPV-associated modes included TRK and/or FPA (Figure 10a, page 10). FMS-associated modes included:

Queenstown — RNAV (RNP) Runway 23

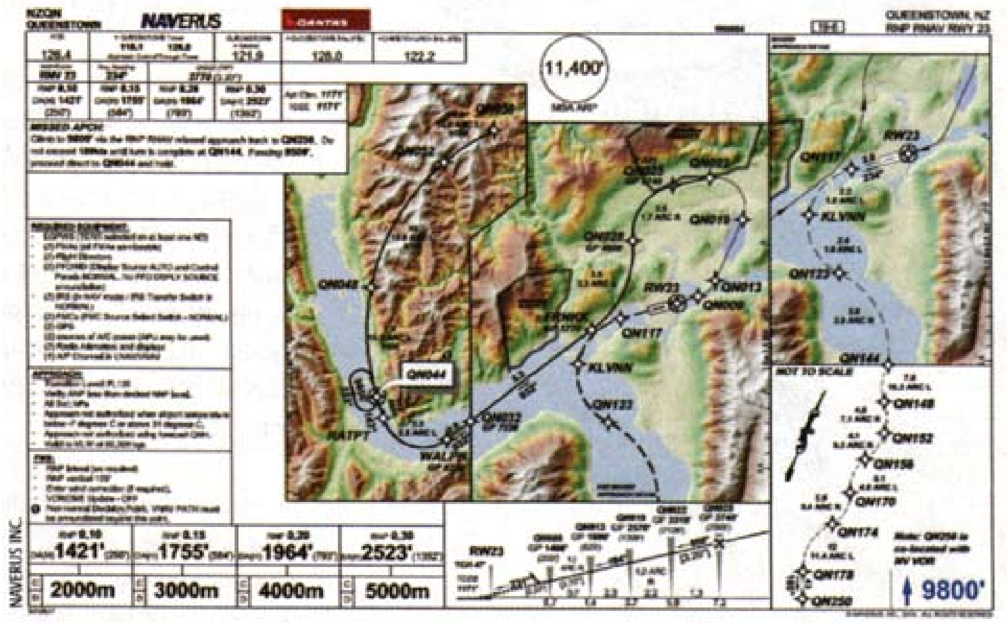

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Figure 5

- NAV or LNAV (lateral navigation), providing guidance along the lateral flight plan (F-PLN); and,

- Destination (DES) and final approach (FINAL APP), or VNAV (vertical navigation), providing guidance along the vertical F-PLN (Figure 10b, page 10).

FINAL APP or LNAV/VNAV are combined modes that guide the airplane along non-ILS approaches, both laterally and vertically.

Third step, the 1990s onward: Guidance functionalities have been affected by the spread of head-up displays (HUDs) in the cockpits, as well as by the enhancement of the associated FMS modes.

The basic flying reference in a HUD is the FPV, which allows the pilot to control the airplane trajectory using outside references such as the runway; flying the HUD is simply flying the airplane trajectory.

The AP/FD FMS-associated modes —DES, FINAL APP or LNAV/VNAV — have been enhanced to improve their guidance performance and thus minimize flight technical error (FTE).

Consequently, the AP/FD modes associated with the FMS are now able to guide the airplane on any type of non-ILS approach, both laterally and vertically, with great precision and thus meet RNP criteria.

Additionally, new specific approach modes have been designed to provide flight crews with identical methods and procedures when flying any straight-in approach, ILS or non-ILS.

These modes are:

- The final approach course (FAC) and glide path (G/P) modes of the Boeing integrated approach navigation (IAN) concept; and,

- The FMS LOC (F-LOC) and FMS glideslope (F-G/S) modes of the Airbus FMS landing system (FLS) concept.

The principle of the FLS is that the FMS computes a virtual beam upstream of the FAF; the course and descent angle of this beam are those of the straight-in non-ILS approach selected in the FMS F-PLN, as stored in the FMS database (Figure 11, page 10).

Consequently, when flying such straight-in approaches with IAN/FLS modes, the

Segmented/Curved Approach
Washington DCA —SAAR RNAV (RNP) Runway 19

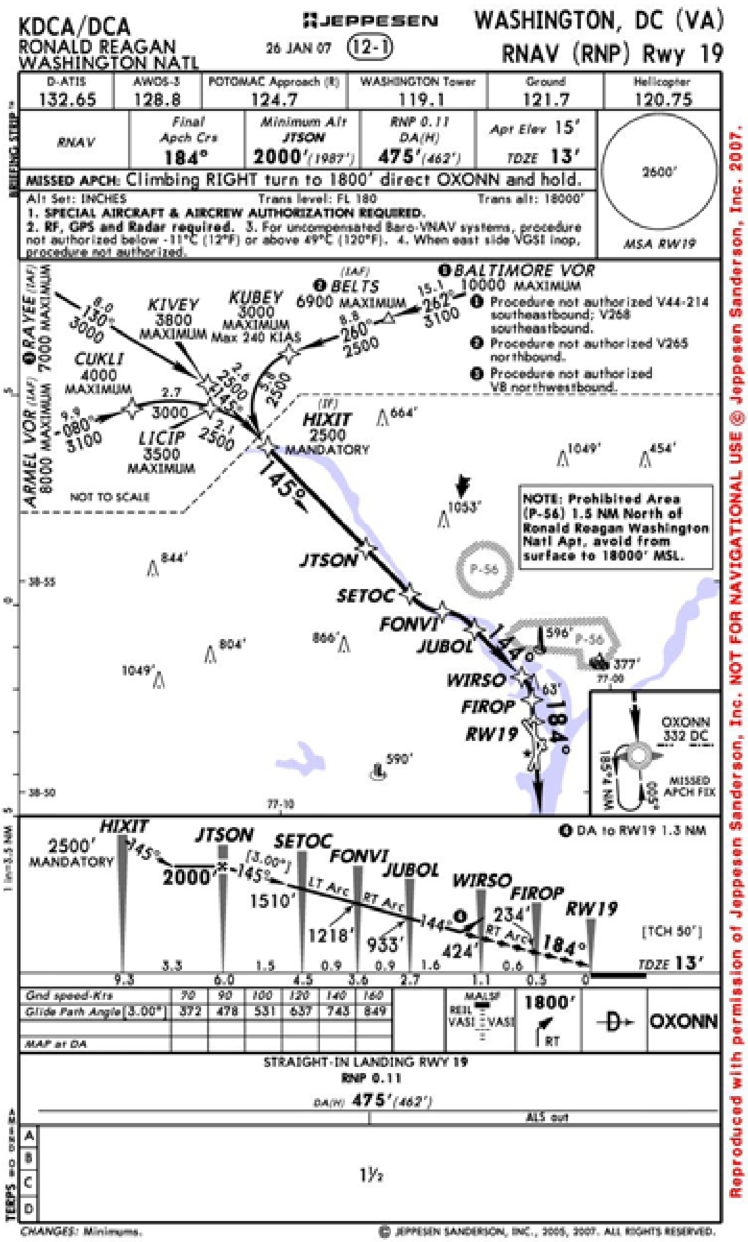

Figure 6

procedures to intercept and track the FLS virtual beam are similar to the procedures used for an ILS.

Display Functionalities: The display functionalities provide the crew with the information required to adequately monitor the progress of the non-ILS approach.

First step, the 1970s: The essential information provided was the position of the airplane relative to the intended lateral trajectory of the approach — that is, the radial to the reference navaid versus the intended approach radial.

This information was provided on the radio magnetic indicator (RMI) for NDB and VOR approaches, and on the HSI for VOR and LOC approaches, which displayed the deviation between the current and intended approach radials (Figure 12, page 11).

Additionally, if DME information was available, a DME readout provided the distance to the associated navaid, which significantly improved crew awareness of the airplane's position.

Crew awareness of the airplane's vertical position versus the intended vertical path was inadequate, however. The crew estimated the airplane's position from information provided by the VSI, altimeter, clock and DME.

Second step, the 1980s: The major advance in display functionalities was the glass cockpit with EFIS displays: the PFD and navigation display (ND), which was directly linked to the FMS and apparently solved the orientation problems some pilots had with the RMI or HSI.

The ND displays the following information:

- The airplane's lateral position relative to the intended lateral path, namely the FMS F-PLN, as well as the final approach trajectory;
- Crosstrack (XTK) error;
- VOR or NDB course-deviation indicators, as reference navaid raw data; and,
- DME distance.

The PFD displays vertical deviation (V/DEV) from the intended final approach descent path, as defined/selected in the FMS (Figure 13, page 11).

Third step, the 1990s onward: Display functionalities, based on the PFD and ND, have been enhanced. This enhancement has been dictated by the tremendous increase in navigation

FMS PROG (Progress) and F-PLN Pages — Typical

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Figure 7

FMS PROG Page with GPS Primary/DATA POS MON Page — Typical

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Figure 8

A300B4 ADI and HSI (1972–1982)

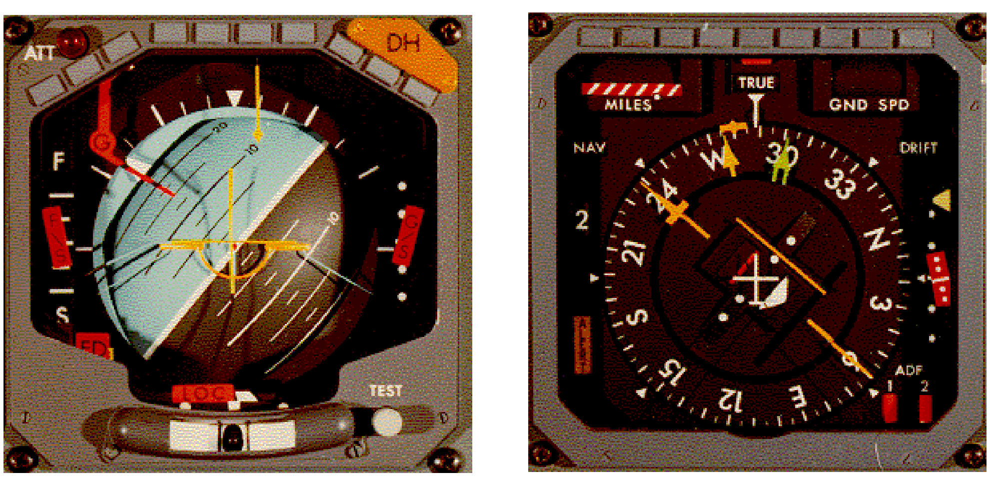

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Figure 9

performance provided by GPS, which has allowed extension of operational capabilities, including reduction of aircraft separation minimums and reduction of approach minimums.

Consequently, most non-ILS approaches can now be flown as precision-like approaches, provided the appropriate information is displayed for crew situational awareness. Furthermore,

PFD Illustrating FPV/FPD and FMS FINAL APP Mode

Figure 10a

PFD Illustrating FPV/FPD and FMS FINAL APP Mode

Figure 10b

the development of the RNP concept has led to specific requirements in terms of monitoring.

The evolution of display functionalities can be summarized as follows:

- On the PFD, lateral deviation scales tailored to RNP requirements;
- On the PFD and ND, displays adapted to IAN or FLS modes (Figure 14, page 11);
- Vertical situation display (VD) added at the bottom of the ND, for enhanced vertical situational awareness (Figure 15, page 12).

FLS — Virtual Beam–Anchor Point

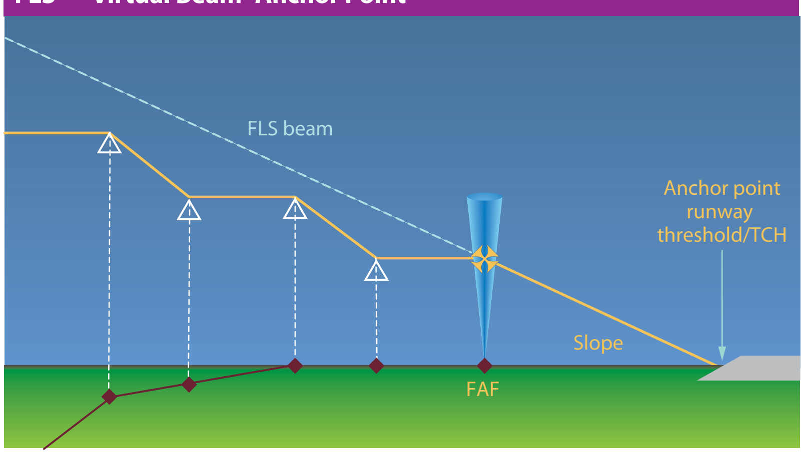

Figure 11

Methods and Procedures

The methods and procedures recommended to fly non-ILS approaches depend upon:

- The nature of the non-ILS approach, ranging from the traditional NPAs of the 1970s to the RNP RNAV approaches of today; and,
- The on-board equipment, from the ADI/HSI/RMI and very basic AP/FD modes of the 1970s to the current glass cockpits with FMS/GPS and LNAV/VNAV-capable AP/FDs.

Additional factors that affect non-ILS approach procedures include the following:

- The position of the FAF, which is either a geographical point on a straight-in approach or a position estimated by the pilot at the end of a procedure turn such as a "teardrop";
- The position of the MAP, which defines the end point of the final approach at which a missed approach must be conducted by the pilot if visual navigation is not achieved. The MAP may be located at, before or beyond the runway threshold; and,
- The nature of the altitude limit — that is, MDA(H) or DA(H).

The 1970s — HSI–DRMI

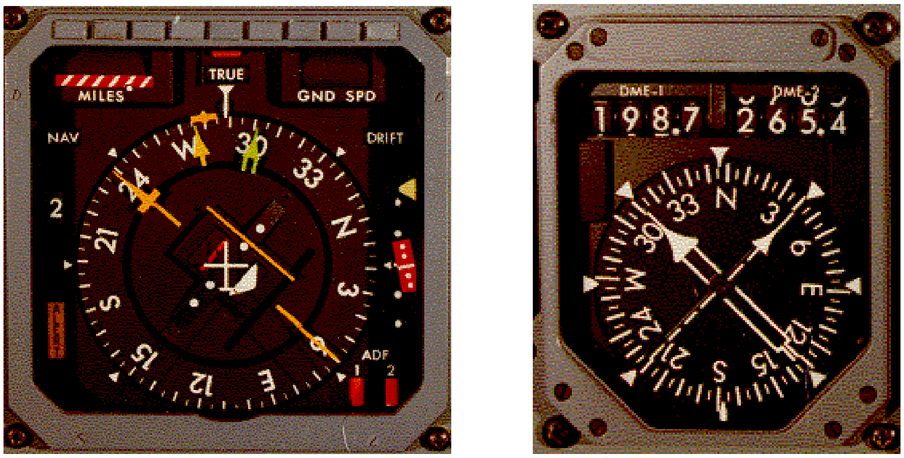

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Figure 12

Airbus EFIS PFD — FINAL APP Mode (V/DEV shown)

©Airbus

Figure 13

The MDA(H) is the minimum descent altitude; descent below the MDA(H) is not allowed in IMC during the approach or during the missed approach. This applies to either:

- Level-off at the MDA(H) during a step-down/dive-and-drive approach until visual references are acquired (Figure 16, page 12); or,
- Initiation of the missed approach above the MDA(H) during a constant descent angle approach if no visual references are acquired, in order not to "duck under" the MDA(H) (Figure 17, page 13).

The DA(H) is, as it states, the decision altitude; if no visual references are acquired when reaching the DA(H), a missed approach must be initiated.

Considering all these factors, the following is a review of the evolution of non-ILS approach procedures:

First step, the 1970s: The non-ILS approaches were the traditional NPAs using NDBs, VORs or LOCs —possibly supplemented by

Boeing EFIS PFD — NPS Scales

© Boeing Commerical Airplanes

Figure 14

Airbus EFIS ND — Vertical Situation Display

© Airbus

Figure 15

DME — as reference navaids, whereas the on-board equipment was conventional in terms of navigation, guidance and display functionalities.

Most airframe manufacturers recommended the use of the autopilot for lateral and vertical control of the airplane during approach. For example, in the 737 flight crew training manual (FCTM), Boeing stated:

"Automatic flight is the preferred method of flying non-ILS approaches. Automatic flight minimizes crew workload and facilitates monitoring the procedure and flight path. During non-ILS approaches, autopilot use allows better course and vertical path tracking accuracy, reduces the probability of inadvertent deviations below flight path and is therefore recommended until suitable visual reference is established on final approach."

Control of the airplane's lateral flight path called for the following unique method:

- Tune reference navaids for the approach;
- Set the RMI selector to ADF (automatic direction finder) for an NDB approach or to VOR for a VOR approach;
- Set the electronic horizontal situation indicator (EHSI) switch to VOR for a VOR or ILS for a LOC-only approach;
- Set the final approach course (CRS) target for the EHSI;
- Use the autopilot roll/lateral modes as follows:
  - HDG mode for an NDB approach, as well as during the intermediate approach; and,
  - VOR for a VOR approach or LOC for a LOC-only approach;
- Disengage the autopilot after visual references are acquired — no later than reaching the MDA(H) — in order to complete the approach visually and manually; and,
- Monitor the lateral trajectory of the airplane using raw data on the EHSI or RMI.

Go-around Decision — Step-down NPA

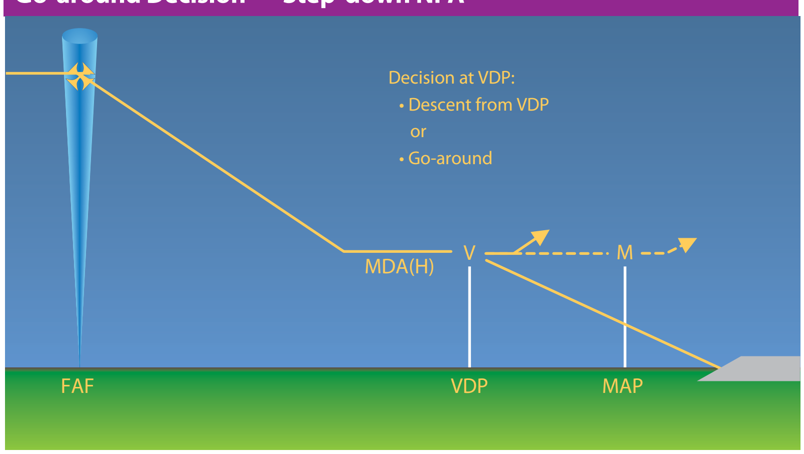

Figure 16

Control of the vertical path of the airplane used two different methods: the step-down method and the constant descent angle method. Both methods assumed that the airplane was being flown in landing configuration and at the final approach speed (VAPP) from the FAF down to the landing or to the initiation of the missed approach.

For non-FMS/non-glass-cockpit airplanes that used NDB/VOR/LOC/DME raw data for approaches, the traditional step-down method was recommended down to MDA(H). The Boeing 737 FCTM described the step-down method as follows:

"Traditional methods of flying non-ILS approaches involve using autopilot pitch or vertical-speed modes on final approach, leveling off at step-down altitudes (if applicable) and at the MDA(H), followed by a transition to a visual final approach segment and landing. Those traditional methods involve changing the flight path at low altitudes and are not similar to methods for flying ILS approaches."

However, a provision for recommending the use of a constant descent angle, as a function of the airplane's estimated groundspeed, had been added, provided a corresponding altitude/distance table was available on the approach chart.

The recommended procedure to fly a constant descent angle NPA was as follows:

- Select V/S — up to 1,500 fpm at more than 1,000 ft above ground level (AGL), 1,000 fpm at the FAF — even if a level flight segment is depicted after the FAF on the chart;
- Level off at the next step-down altitude(s); monitor and make the appropriate altitude/distance callouts;
- Select V/S — 1,000 fpm for flying the last step-down segment to the MDA(H); and,
- If the airfield is not in sight at an altitude equal to MDA(H) plus 10 percent of the descent rate — for example, add 100 ft to the MDA(H) for a typical 1,000 fpm rate of descent — reduce V/S to ensure that the airplane does not descend below the published MDA(H); this might result in reaching the MDA(H) past the published or estimated visual descent point (VDP).

The VDP is either depicted on the approach chart as a "V" (Figure 18) or estimated by the pilot. The VDP is located along the final approach trajectory at a distance from the runway threshold that allows a 5 percent — 3-degree — descent path to the runway; the descent is initiated when crossing the VDP at the MDA(H).

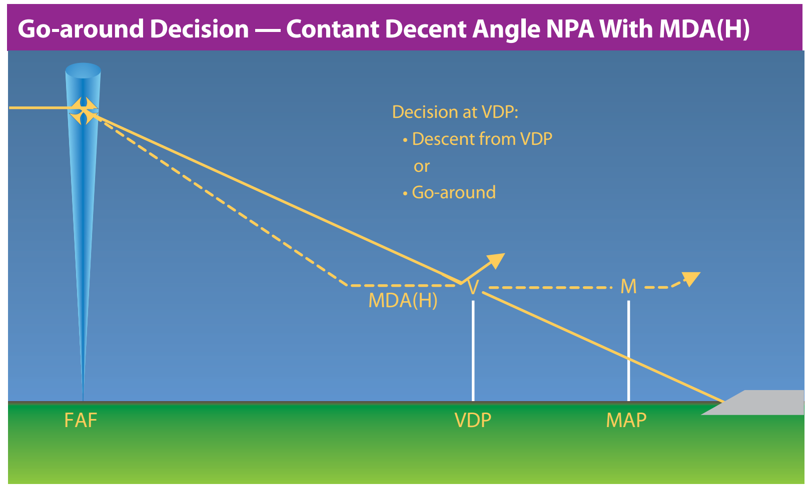

Figure 17

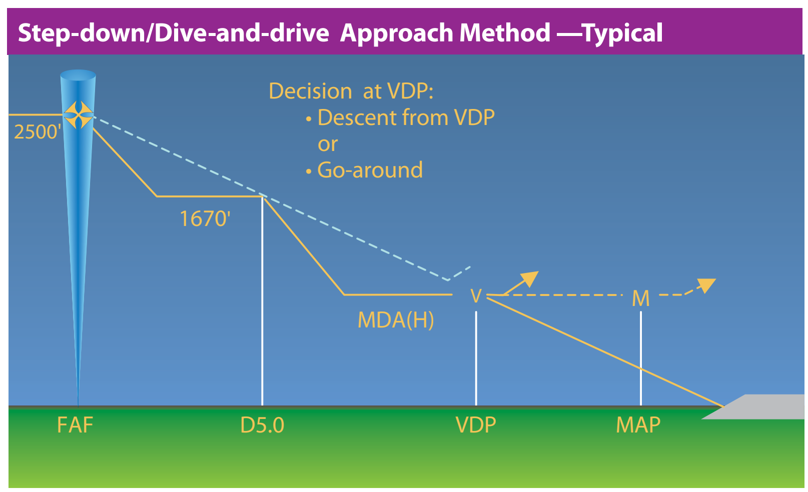

Figure 18

The VDP is the last point from which a stabilized approach to the runway can be conducted. When not provided on the chart, the position of the VDP can be estimated by the crew either as a distance to the runway threshold or a time from the FAF.

This method was recommended for all NPAs by some operators that flew many NDB approaches without DME and without published vertical descent angle or rate of descent information.

The traditional step-down approach technique had the following drawbacks:

Kathmandu — VOR DME Runway 02 — Multi-stepdown Approach

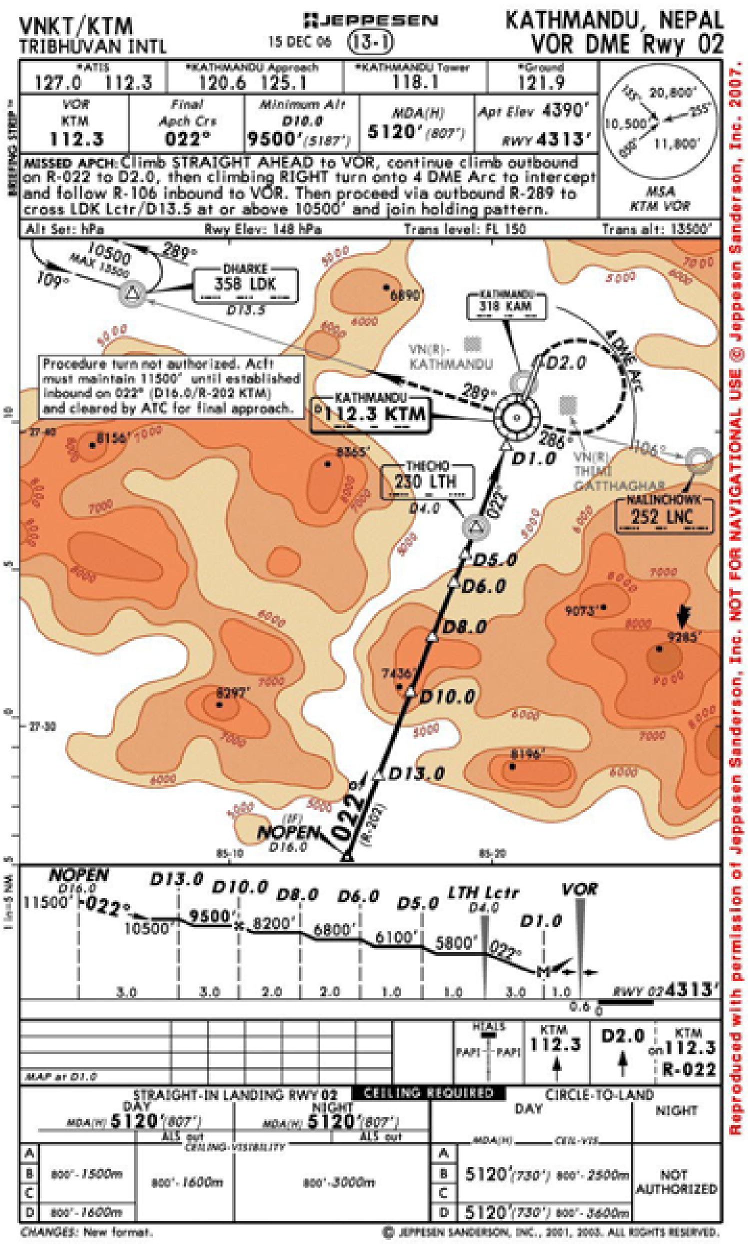

Figure 19

- The airplane was never stabilized during the final approach; the pitch attitude needed to be changed even at low altitudes; thus, thrust and pitch had to be continuously adjusted; and,

- The airplane reached MDA(H) in quasi-level flight either before the VDP or after the VDP.

Consequently, the acquisition of visual references and the perspective view of the runway were affected by the airplane's pitch attitude, which was significantly greater than the nominal pitch attitude observed when the airplane is established on a 3-degree glide path. Furthermore, when acquiring visual references beyond the VDP, the pilot might be tempted to continue the final, visual segment of the approach, which could result in a high descent rate.

The technique led to unstabilized approaches which, as line experience showed, led to off-runway touchdowns, tail strikes and runway excursions/overruns.

The preceding discussion is illustrated by the VOR/DME approach to Runway 02 at Kathmandu, Nepal (Figure 19). Until recently, most operators flew this approach using the traditional step-down procedure. The typical result was that, during most of the approach, the airplane was not stabilized, which was the cause of a number of CFIT accidents and approach-and-landing incidents/accidents.

Regarding the second method, the constant descent angle, Boeing states in the 737 FCTM:

"The methods which provide a constant angle approach reduce the exposure to crew error and, thus, CFIT accidents. These methods also make it much easier for the crew to achieve a stabilized approach to a landing, once visual reference to the runway environment has been established."

This method requires the crew to compute an adequate V/S to fly from the FAF to the VDP on a constant descent angle (Figure 20, page 15). This V/S is a function of the average groundspeed of the airplane during the approach.

On some approach charts, constant descent angle tables, showing V/S versus groundspeed, are provided. If such tables are not provided, the pilot estimates the time between the FAF, at the FAF altitude, and the VDP, at the MDA(H) or DA(H), and establishes the adequate V/S.

Consequently, no later than during the intermediate approach, the pilot:

- Estimates the average groundspeed for the final approach;

- Determines from the published table or by computation the constant V/S to be flown during the final approach; and,

- Estimates the position of the VDP, if not published.

Reaching the FAF, the pilot:

- Selects the AP/FD V/S mode on the flight control unit (FCU) or mode control panel (MCP) and enters the V/S target previously determined; for airplane models not featuring a V/S mode, the pitch mode is used and the pitch attitude is adjusted to obtain the desired V/S; and,

- Monitors the descent using either the altitude/distance check points, if a DME is available, or the elapsed time from the FAF to a given altitude, with increased monitoring when approaching the MDA(H)/VDP.

No descent below MDA(H) is allowed if visual references are not acquired; a missed approach must be initiated immediately. Level-off at MDA(H) should not be considered, because delaying the go-around decision until the MAP would not allow, with most published MAP positions, a stabilized visual segment and landing.

The main advantages of the constant descent angle approach technique are:

- The final approach is stabilized — pitch attitude, speed, thrust and pitch trim remain constant;

- When reaching the VDP with visual references acquired, the perspective view of the runway is similar in most cases, thus allowing the pilot flying to properly determine if a normal visual approach to the runway can be continued;

- The transition from the instrument to the stabilized visual approach is continuous; and,

- The monitoring of the vertical flight path during the approach is simple and continuous.

Constant-angle Approach Method — With MDA(H) or DA(H)

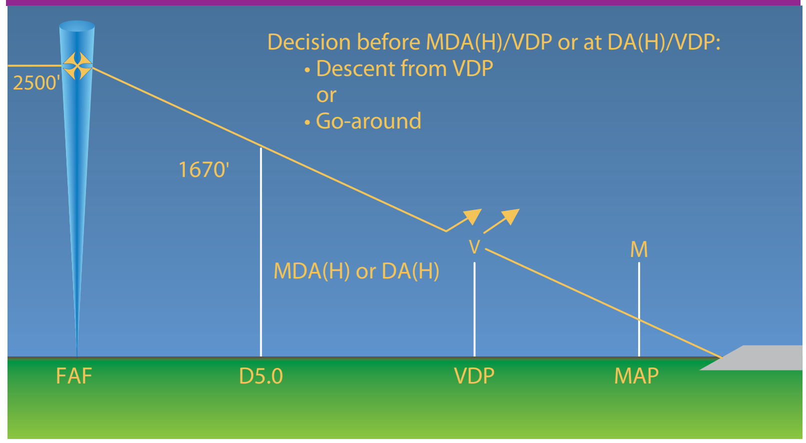

Figure 20

Second step, the 1980s: Non-ILS approaches included the traditional NPAs as well as RNAV approaches.

The on-board equipment was upgraded with:

- Glass cockpits featuring EFIS;

- FMS with high-performance airplane position computation, with MIX IRS position enhanced by DME/DME or VOR/DME corrections; and,

- AP/FD with basic TRK/FPA modes and FINAL APP, or LNAV/VNAV, combined modes.

All these systems — the basic TRK/FPA modes, the display of the FPV on the PFD and the flight planning capabilities of the FMS — favored the concept of *trajectory*. Consequently, for a non-ILS approach, lateral and vertical guidance, referenced from the FMS position, could be provided along a trajectory retrieved from the FMS navigation database.

The AP/FD LNAV/VNAV or FINAL APP modes could track this approach trajectory, thus ensuring that XTK error or lateral deviation (L/DEV) and V/DEV were kept to zero (Figure 21, page 16).

The procedures and methods used by operators during this period varied. Some operators still recommended the traditional step-down method. However, they were taking benefit from

Lateral Trajectory — XTK–L/DEV and Vertical Trajectory V/DEV

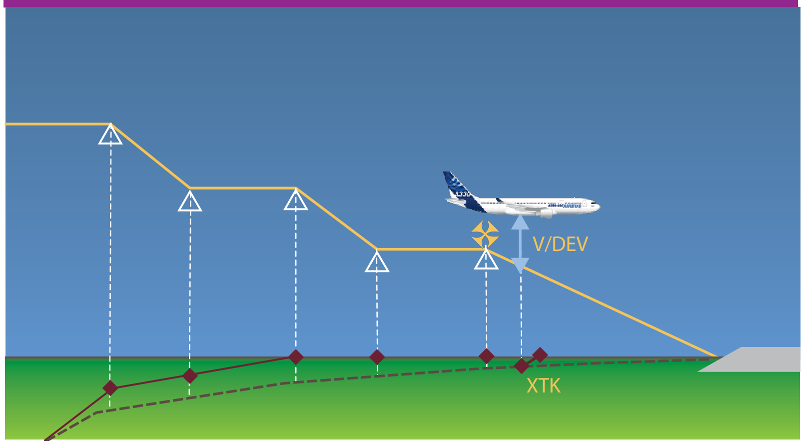

Figure 21

the FMS NAV or LNAV modes and used the EFIS ND ARC or MAP display mode, which provided the airplane's position on the plan view of the approach.

Many operators had adopted the procedures recommended by the airframe manufacturers, which took benefit of the FMS features to support the constant descent angle approach technique.

Two precautions were essential to fly those approaches with full use of the FMS. First, the pilot had to ensure that the FMS position was accurate and that its accuracy was within the tolerances of the approach area, typically within 0.3 nm.

FMS position accuracy actually dictated the strategy that would be used for the completion of the approach, including the AP/FD modes selected to fly the approach and the ND display mode selected to monitor the approach.

If FMS navigation accuracy was found to be within the applicable tolerances, the AP/FD FMS-related modes LNAV/VNAV or FINAL APP might be used for the completion of the final approach, and the EFIS ND ARC or MAP display modes might be used to monitor the completion of the approach, along with the V/DEV indication on the PFD.

If FMS navigation accuracy was found not to be within the applicable tolerances, the AP/FD TRK/FPA modes had to be used to track the lateral and vertical trajectory of the airplane, and the EFIS ND ROSE display mode had to be used, at least by the pilot flying; the pilot monitoring might still use the MAP display, with overlay of raw data, for enhanced situational awareness.

Indeed, an inaccurate FMS position would directly affect the performance of the AP/FD FMS guidance and render the EFIS ND MAP display very misleading. Figure 22 shows an FMS navigation accuracy check using the FMS program (PROG) page and the ND in the ARC display mode.

FMS Navigation Accuracy Check
Airbus FMS PROG Page and ND with ARC Display Mode

Figure 22

As a second precaution, the pilot had to check the quality of the FMS navigation database, in order to ensure that the final approach inserted in the FMS F-PLN by the pilot was correct. The final approach could not be modified by the crew when the airplane was between the FAF and the MAP.

In other words, the crew had to check that the series of waypoints that defined the final approach route, the crossing altitudes and the FPAs of the various legs provided on the FMS multifunction control display unit (MCDU) route legs (RTE LEGS) or F-PLN page were consistent with the published procedure.

If the two precautions were satisfied, then the FMS, its associated guidance modes and display functionalities could be used to complete the final approach.

On some airplanes, the FPV was provided on the EFIS PFD. The FPV was selected during non-ILS approaches because it was the best adapted flying reference for a constant descent angle stabilized segment of trajectory.

The constant descent angle approach technique can be summarized as follows:

- Initial approach:
  - Check the FMS navigation accuracy and select the reference navaid raw data on the ND;
  - Check that the final approach inserted on the FMS MCDU matches the published procedure;
  - Select the FPV, if available, as the flying reference; and,
  - Check the DA on the flight mode annunciator (FMA), as inserted in the FMS.
- Intermediate approach:
  - Decelerate and configure the airplane in the landing configuration;
  - Intercept the final approach radial; if the air traffic control (ATC) clearance corresponds with the FMS F-PLN, use the NAV mode; if ATC provides radar vectors, use the HDG or TRK mode and the direct-to (DIR TO) mode to intercept the inbound radial or course on the FMS;
  - Monitor the interception, using the ND in ARC or MAP display mode; and,
  - During a vectored approach, when ATC clears the airplane to intercept the final approach course, press the approach (APPR) pushbutton on the FCU or arm the NAV/LNAV mode on the MCP.
- Final approach:
  - Ensure that the airplane is established in landing configuration at VAPP prior to the FAF;
  - Upon reaching the FAF, check that the LNAV/VNAV or FINAL APP mode engages, or select VNAV if applicable;
  - Set the missed approach altitude in the FCU or MCP;
  - Monitor to ensure that the airplane is properly guided along the FMS final approach, using the ND in the ARC or MAP display modes and V/DEV on the PFD; and,
  - When reaching DA(H), if visual references are acquired, disengage the AP and hand-fly the visual segment, usually maintaining the same descent path; if visual references are not acquired, initiate a missed approach.

Note: In some cases, the final approach vertical path is not properly coded in the database; this can be detected by the check done during the initial approach. In such a case, the AP/FD modes used to fly the approach should be NAV/FPA, FPA being selected to the final approach descent angle, when approaching the FAF. Published MDA(H)s may be used as DA(H)s if allowed by local regulations, provided VNAV or an equivalent mode is used on final approach.

Manufacturers in the 1980s recommended that operators fly stabilized approaches and constant descent angle approaches. Figure 23 illustrates the various steps of the constant descent angle approach technique.

A stabilized approach means that the airplane is on the proper lateral/vertical path, in landing configuration and at the final approach speed and therefore with appropriate thrust setting and pitch trim, thus enhancing the pilot's awareness of:

- The horizontal and vertical situation;
- Airspeed; and,
- Energy, with thrust being maintained close to the setting required to fly the final approach descent path at the final approach speed.

A constant descent angle approach:

- Ensures an approach profile that provides greater obstacle clearance along the final approach course;
- Offers an approach technique and procedure similar to those for conducting an ILS approach and missed approach;
- Significantly reduces pilot workload during final approach, which enhances situational awareness;
- Ensures an adequate airplane pitch attitude that facilitates the acquisition of visual references when approaching DA(H); and,
- Is more fuel-efficient and reduces noise.

Consequently, it can be stated that the non-ILS approaches — traditional NPAs and RNAV

Constant-angle Descent Approach Technique

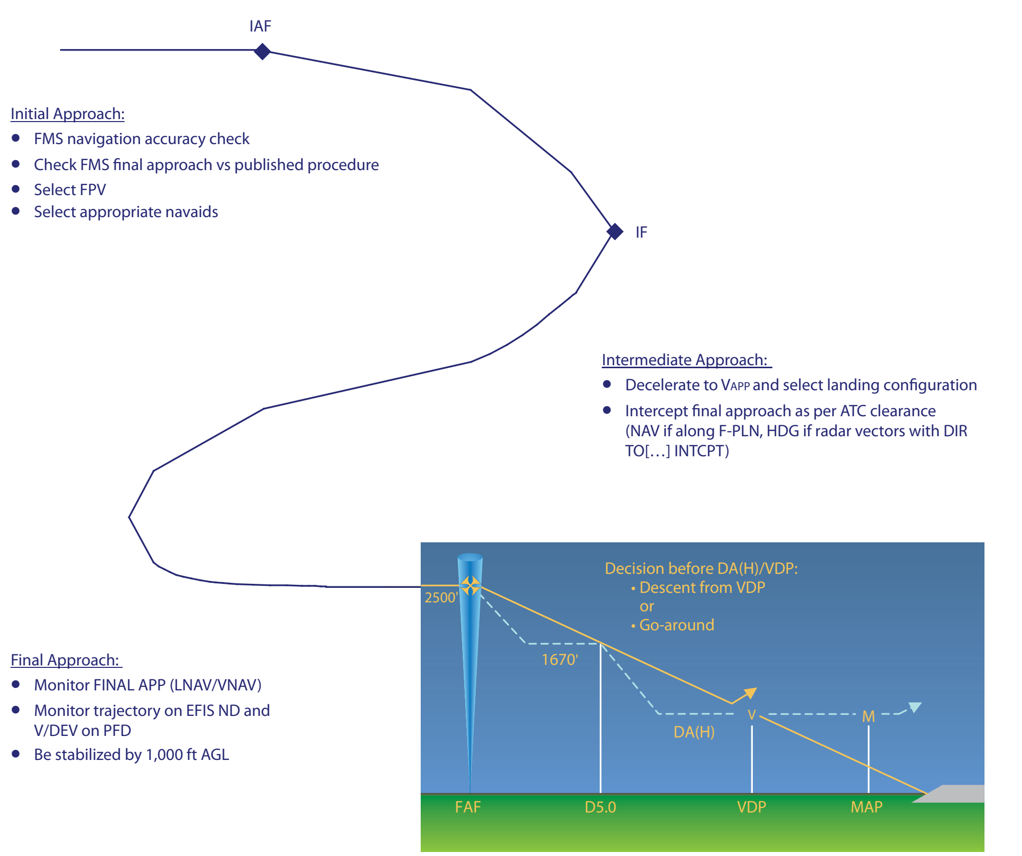

Figure 23

approaches — can be flown like ILS approaches due to the stabilized/constant descent angle technique provided by an appropriate procedure and guidance modes — LNAV/VNAV or NAV/FPA — and the use of a DA(H) instead of an MDA(H).

However, in the 1980s, non-ILS approaches, such as the VOR/DME approach to Kathmandu (Figure 24), were still being flown using the step-down/dive-and-drive technique, and there were several CFIT accidents.

Some operators divided the vertical profile of the Kathmandu approach into three successive constant descent angle segments, while still complying with all the step-down altitudes, as follows:

- A 3.1-degree constant descent angle segment from NOPEN, the intermediate fix (IF), to the FAF at D10.0;
- A 6.11-degree constant descent angle segment from D10.0 to D5.0; and,
- A 3.17-degree constant descent angle segment from D5.0 to the MAP at D1.0.

Most VNAV modes provide descent angles as steep as 4.5 degrees. Consequently, some operators now fly the Kathmandu final approach using the NAV/FPA modes, with landing configuration and VAPP stabilized before NOPEN, then as follows:

- FPA is set to 3.1 degrees in the FCU or MCP at 0.2 nm from NOPEN;
- FPA is set to 6.1 degrees — and speed brakes are extended due to the higher descent angle — at 0.2 nm from D10.0; and,
- FPA is set to 3.2 degrees — and speed brakes are retracted — at 0.2 nm from D5.0.

This multi-segment constant descent angle technique is, by far, more "friendly" than the traditional multi-step-down technique; it significantly enhances the vertical situation awareness of the crew.

Kathmandu — VOR DME Runway 02 — Constant-angle Descent Segments

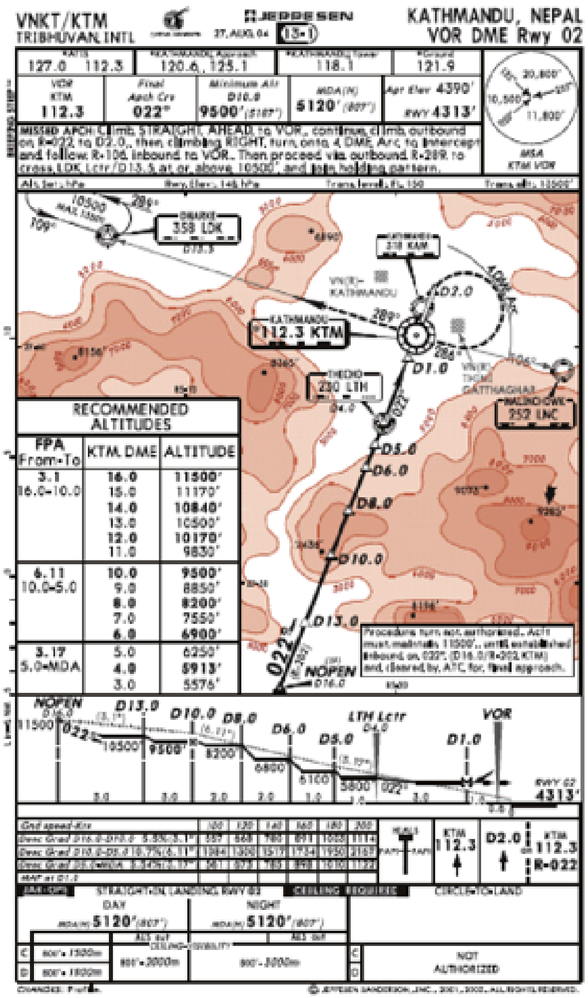

Figure 24

Third step, the 1990s onward: The advent of GPS has affected the way non-ILS approaches are flown and has allowed full implementation of the RNP concept.

Furthermore, the enhancement of display functionalities — VD, for example — and guidance functionalities — LNAV, VNAV, FLS, IAN, HUD, for example — has further reinforced the constant descent angle/stabilized final approach technique.

Thus, all non-ILS approaches can now be flown like ILS approaches and, due to GPS, may be considered as precision-like approaches.

Two methods/flying techniques are currently recommended, depending upon the

Airbus EFIS PFD With RNP Deviation Scales

© Airbus

Figure 25

RNP RNAV Approach — Baro VNAV — Minimum OAT

Figure 26

geometry of the approach and the airplane equipment.

One technique uses the FINAL APP or LNAV/VNAV AP guidance modes. It is applicable to all types of non-ILS approaches — that is, traditional NPAs, RNAV and RNP RNAV approaches— including straight-in, segmented or curved approaches that are properly coded in the FMS navigation database.

The procedure is similar to the one used by operators in the 1980s. The same flying technique applies, and the same precautions must be taken regarding checking FMS navigation accuracy; however, since GPS is able to monitor its performance and integrity, some alerts automatically advise the crew when/if:

- Navigation performance is not satisfactory;
- GPS primary navigation capability is lost; or,
- The RNP level is not satisfied.

The same precautions also must be taken regarding checking the proper coding of the final approach in the FMS navigation database.

The following points must be considered:

- If an RNP RNAV approach is flown, the deviations displayed on the PFD are scaled to the RNP (Figure 25);
- The approaches are flown down to DA(H) or MDA(H), depending on local regulations, and,
- Because barometric VNAV (BARO VNAV) is used and guides the airplane on the FPA provided by the FMS, the BARO VNAV guidance will guide the airplane on a shallower or steeper flight path than expected if the outside air temperature (OAT) is significantly lower or higher than standard.

This explains why, on approach charts such as the RNAV RNP approach to Runway 13R at Kennedy International (Figure 26), a minimum OAT is specified for BARO VNAV operations in order to maintain the required minimum

Airbus — EFIS PFD — FLS Modes

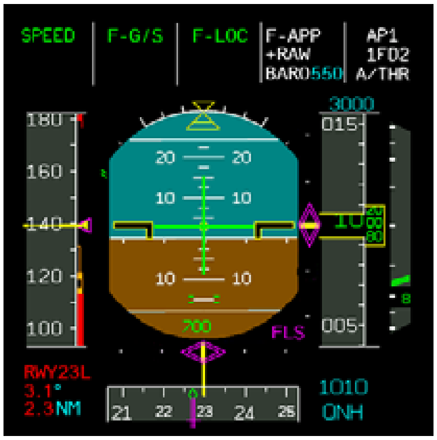

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Figure 27

Boeing — EFIS PFD — IAN Modes

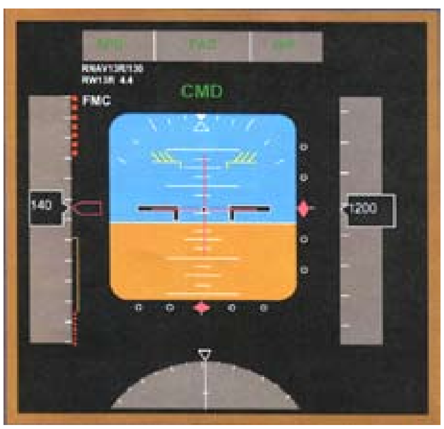

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Figure 28

obstacle clearance. A maximum OAT also may be specified.

The other technique uses the Airbus FLS guidance mode (Figure 27) or the Boeing IAN guidance mode (Figure 28) for all straight-in non-ILS approaches coded in the FMS navigation database.

The main goal of the FLS/IAN modes is to allow straight-in non-ILS approaches to be flown like ILS approaches, which means that the procedures recommended to aircrew to fly non-ILS and ILS approaches are nearly identical. The procedures have the same sequence of actions, controls and displays.

However, because the FLS and the IAN are based upon approach procedures stored in the FMS navigation database and the performance of the guidance is linked to FMS navigation accuracy, the same two precautions apply:

- Proper coding of the approach must be checked; and,
- FMS navigation accuracy must be checked.

The final approach is completed with the same procedures used for an ILS approach. However, when reaching the DA(H) or MDA(H), the pilot must disengage the AP and hand-fly the visual segment of the final approach down to landing since there is no autoland capability.

With these flying techniques, all non-ILS approaches should no longer be considered as NPAs but as precision-like approaches, if flown accordingly.

Today, most operators still use the step-down technique, with all its drawbacks, to fly the VOR/DME approach to Kathmandu. However, some operators use the NAV/FPA modes on three successive constant descent angle segments — that is, 3.1 degrees, 6.11 degrees and 3.17 degrees — which has significantly increased the safety of this approach.

Tomorrow, a curved RNP RNAV approach, with a single constant descent angle from the FAF to the runway might be available. Figure 29, page 22 shows such an approach, to Kathmandu's Tribhuvan International Airport, developed during an Airbus study. The approach would be flown in LNAV/VNAV or FINAL APP modes down to the DA, provided that the ANP of the FMS is within RNP 0.3.

When such an RNP RNAV approach is available, along with the associated procedures, pilots will really fly precision-like approaches into Kathmandu.

Conclusion

The completion of a non-ILS approach is one of the most challenging and demanding phases of flight, and requires proper planning and

Kathmandu RNAV (RNP) SAAR Runway 02 — Airbus Study

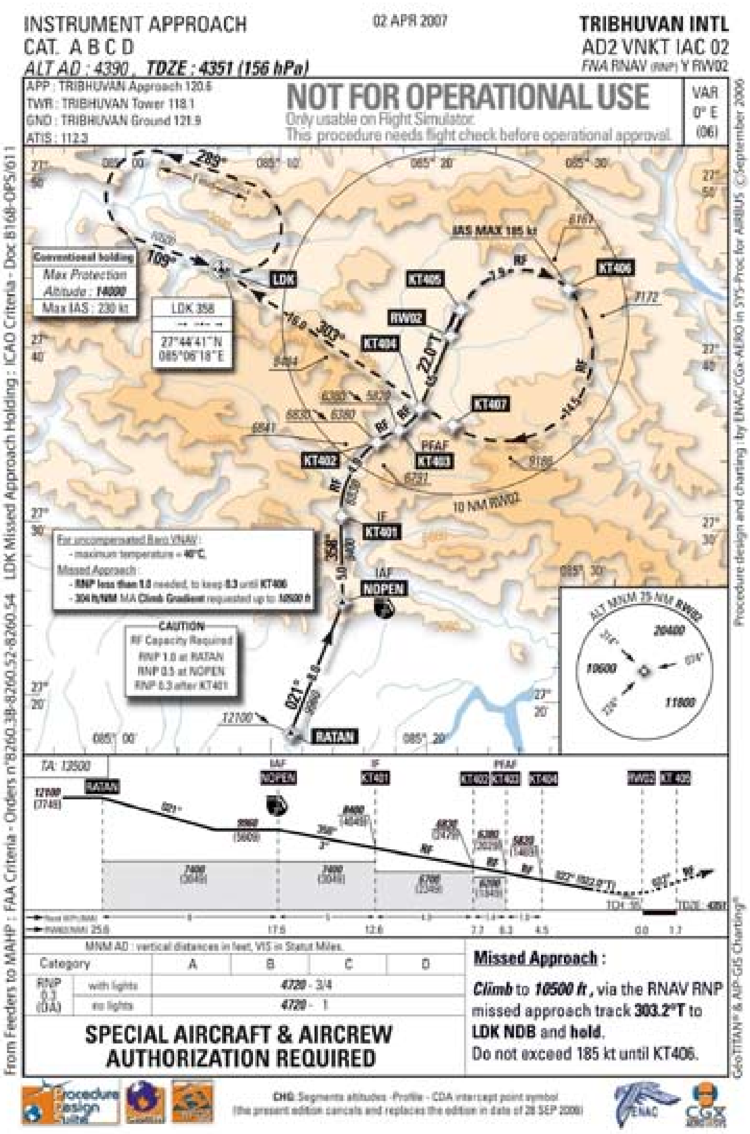

Figure 29

significant strictness by the crew in the conduct of the approach — including task sharing, coordination, risk awareness and decision making.

The methods and procedures recommended to fly non-ILS approaches have changed significantly in the past decades. Despite the flaws, weaknesses and drawbacks found in line experience, the step-down/dive-and-drive method is still widely used, even in airplanes featuring the latest technology. Today's constant descent angle/stabilized final approach technique significantly raises the safety level of this flight phase.

With the increased use of GPS and the latest technology glass cockpits, all non-ILS approaches — from traditional NPAs to RNP RNAV approaches — may be flown using the constant descent angle technique.

The resulting procedures are very similar to those recommended for conducting ILS approaches; furthermore, the extremely high accuracy of GPS and the high performance of the lateral and vertical modes of the AP/FD enable pilots to conduct non-ILS approaches very precisely.

This fully explains the change in the operational vocabulary from *nonprecision* approaches to *ILS-like* approaches to *precision-like* approaches. ●

Airbus, Boeing Commercial Airplanes, Bombardier Aerospace, Jeppesen, Naverus, Northwest Airlines and Qatar Airways contributed to the research and preparation of this report.

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Abbreviations

ADF	automatic direction finder
ADI	attitude director indicator
AGL	above ground level
ANP	actual navigation performance
AP	autopilot
ATC	air traffic control
BARO VNAV	barometric vertical navigation
CFIT	controlled flight into terrain
CRS	course
DA(H)	decision altitude/height
DES	destination
DME	distance measuring equipment
EFIS	electronic flight instrument system
EHSI	electronic horizontal situation indicator
FAC	final approach course
FAF	final approach fix
FCTM	flight crew training manual
FCU	flight control unit
FD	flight director
F-G/S	flight management system–glideslope
F-LOC	flight management system–localizer
FLS	Airbus flight management system landing system
FMS	flight management system
FPA	flight path angle
FPD	flight path director
FMA	flight mode annunciator
F-PLN	flight plan
FPV	flight path vector
FTE	flight technical error
G/P	glide path
GPS	global positioning system
HDG	heading
HSI	horizontal situation indicator
HUD	head-up display
IAN	Boeing integrated approach navigation
IAP	instrument approach procedure
IF	intermediate fix
ILS	instrument landing system
IMC	instrument meteorological conditions
INS	inertial navigation system
IRS	inertial reference system
L/DEV	lateral deviation
LNAV	lateral navigation
LOC	localizer
LS	landing system
MAP	missed approach point
MCDU	multifunction control display unit
MCP	mode control panel
MDA(H)	minimum descent altitude/height
NAV	navigation
ND	navigation display
NDB	nondirectional beacon
NPA	nonprecision approach
OAT	outside air temperature
PFD	primary flight display
PROG	program
RMI	radio magnetic indicator
RNAV	area navigation
RNP	required navigation performance
RTE	route
TRK	track
VAPP	final approach speed
VDP	visual descent point
VD	vertical deviation display
V/DEV	vertical deviation
VNAV	vertical navigation
VOR	VHF omnidirectional radio
V/S	vertical speed
VSI	vertical speed indicator
XTK	crosstrack