Flight Operations Briefing Notes

Industry Safety Initiatives

From Non-Precision to Precision-like Approaches

This Flight Operations Briefing Note is an expanded version of an article published in the Flight Safety Foundation AeroSafety World journal, issue October 2007. This article is part of a series of four articles developed at the initiative of the Flight Safety Foundation International Advisory Committee, by a team composed of Airbus, Boeing and Honeywell.

I Introduction

The methods and operational procedures which have been defined by airframe manufacturers, airlines and other operators for pilots to fly non-ILS approaches have evolved in time, over the past 35 years.

The evolutions of these procedures have been dictated by the following factors:

- The way non-precision approaches (NPA's) or precision-like approaches are defined;
- The navigation sensors used on board the aircraft; and,
- The on-board instruments provided to:
  - Fly the approach; and,
  - Monitor the approach.

The combination of these factors has enabled to rationalize 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 CFIT or land-short during final approach.

This evolution and rationalization have been achieved schematically in three steps in time, considering an origin circa 1970:

- First step: the seventies – Non-precision approaches (NPA's);
- Second step: the eighties – NPA's towards constant-angle / stabilized approaches; and,
- Third step: the nineties and further – Precision-like approaches.

II Main Factors Involved in Non Precision Approaches

Any type of instrument approach procedure (IAP) into a runway is a lateral and vertical trajectory defined so as to be flown by aircrafts in IMC down to the applicable minima's where, at the latest, the required visual references must be acquired by the pilots so as to safely continue the approach and land.

The instrument approaches are supported by various types of navigation systems and may be divided into two types:

- The ILS (or, more generally, the LS) approaches: These approaches are materialized by a "physical" lateral and vertical beam down to the runway, allowing to consider autolands; and,
- The non-ILS approaches (i.e., NPA's, RNAV approaches, precision-like approaches): These approaches are materialized by a lateral course or pattern supported by a radio navaid, 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 (typically, IRS / GPS / FMS / …), the RNAV point-to-point method of navigation – not dependent on navaids – has allowed more flexibility in the definition of the final approach lateral and vertical path.

In all cases, the final approach starts from a Final Approach Fix (FAF) and ends at the Missed Approach Point (MAP), or at a MDA(H) or DA(H).

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

The methods and procedures provided to aircrews by manufacturers, operators and airlines to fly instrument approaches in IMC have varied in time since they depend upon two main factors: The nature of the approach and the onboard equipment.

II.1 The "Nature" of the non-ILS Approach

Traditional NPA's in the Seventies

These approaches are referenced to a ground radio navaid used to materialize the final approach trajectory or pattern. These navaids, since the last 30 years, were typically a NDB, VOR or LLZ – coupled or not to a DME.

Note:

LLZ refers to LOC-only and to LOC-back-course beams.

These approaches are named « non-precision » because the overall performance of these approaches is dictated by:

- The performance of the navaid, itself; the typical accuracy of these navaids is:
  - NDB : +/_ 5 degrees;
  - VOR : +/- 3 degrees;
  - LLZ : +/- 0.2 degree; and
  - DME : 0.2 nm or 2.5 % of distance.

- The location of the navaid on the airfield, or close to the airfield relative to the extended runway centerline. This location affects the approach pattern and the difficulty to fly the approach and, hence, the flight accuracy.

  Refer to **Figure 1** through **Figure 3** for illustrations of typical navaids' locations and associated operational aspects.

  The following navaid locations may be found:
  - Navaid located on the airfield, on the extended runway centerline, allowing a straight-in approach with no offset (**Figure 1**).
  - Navaid located on the airfield, abeam the runway, associated to an approach pattern (teardrop procedure turn) with an offset final segment (**Figure 2**).
  - Navaid located abeam the extended runway centerline, associated to a significantly offset final approach trajectory (e.g., over 30 °, usually due to surrounding terrain) (**Figure 3**).

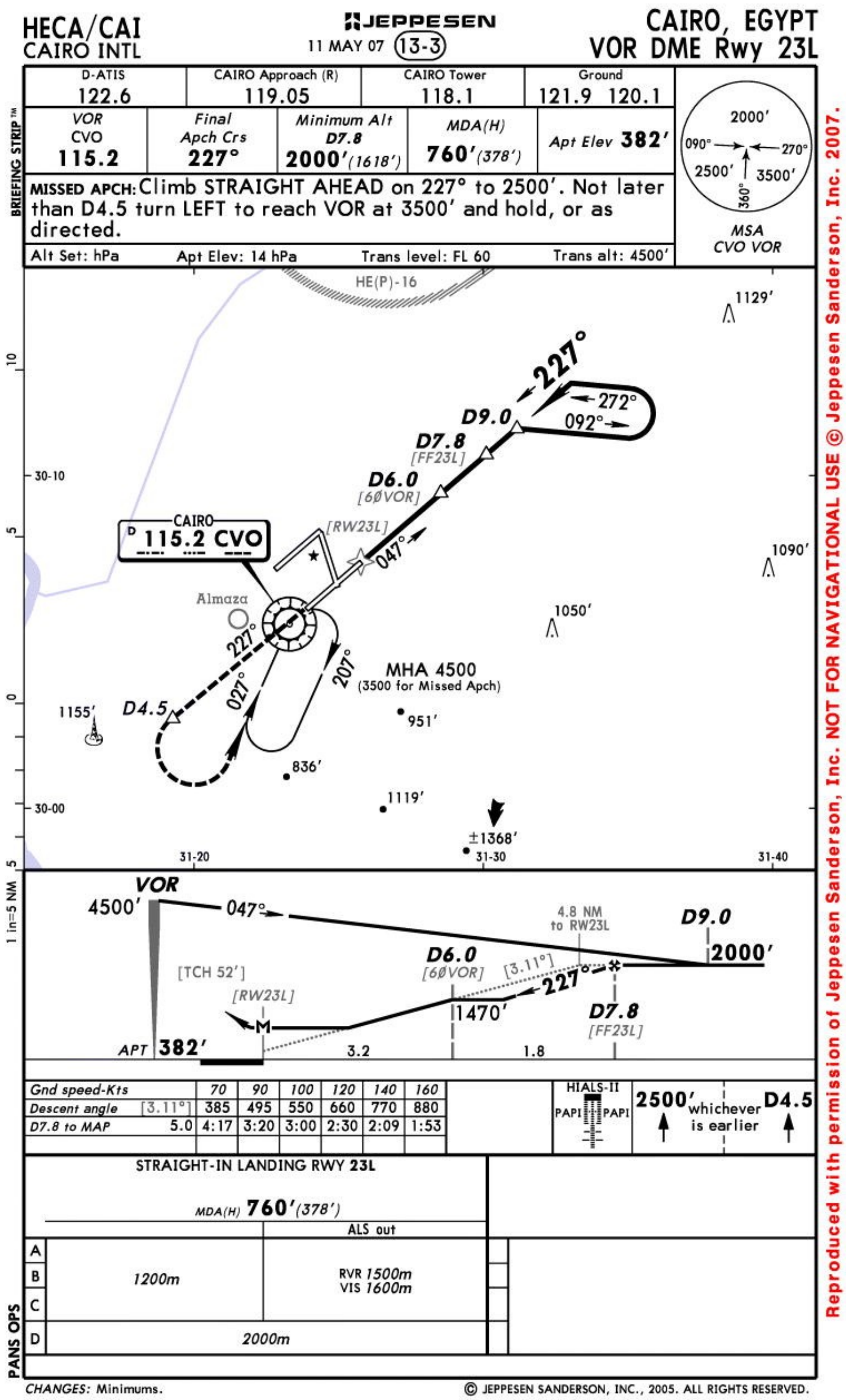


Figure 1

Cairo - VOR DME Rwy 23 L

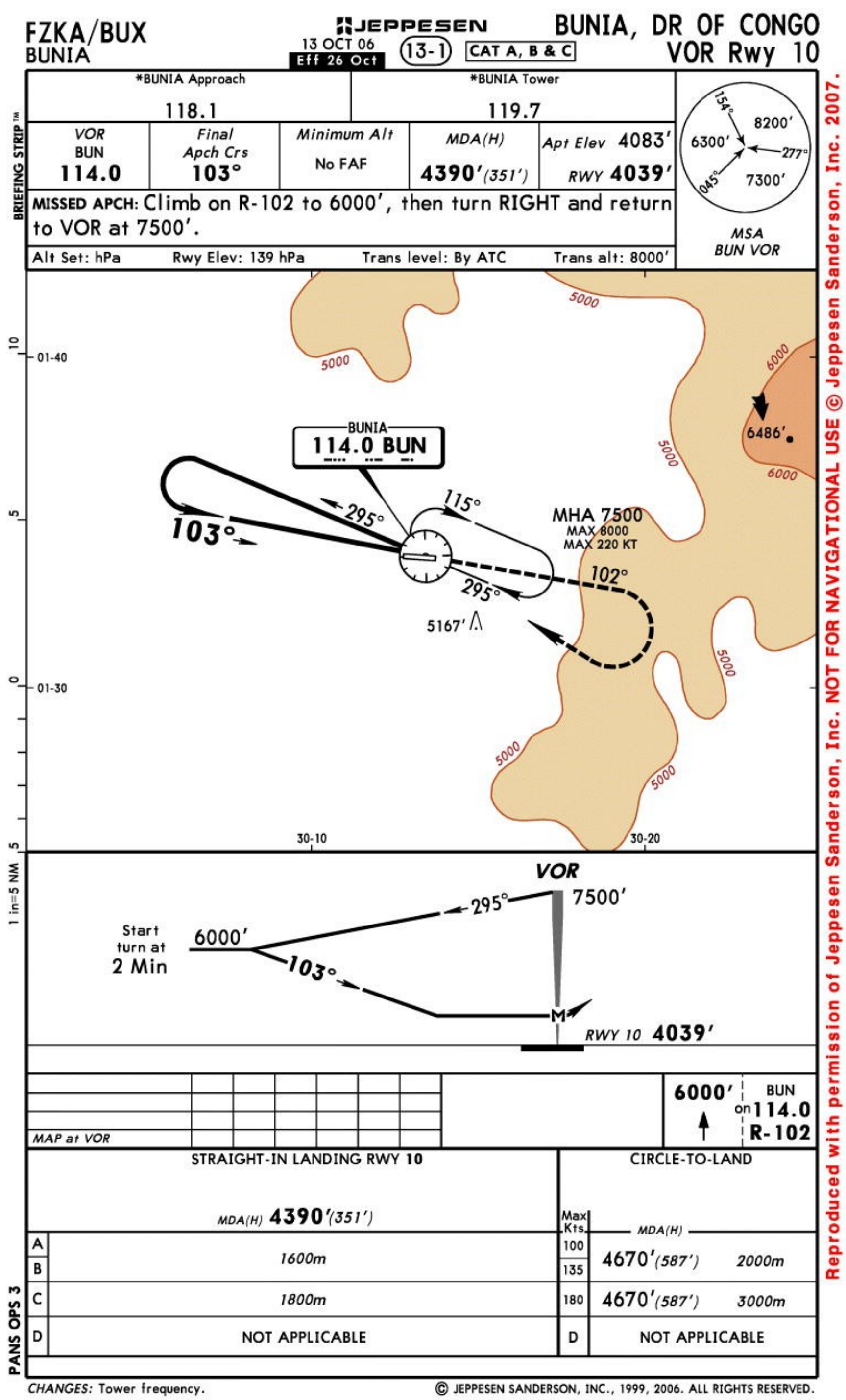


Figure 2

Bunia – VOR Rwy 10

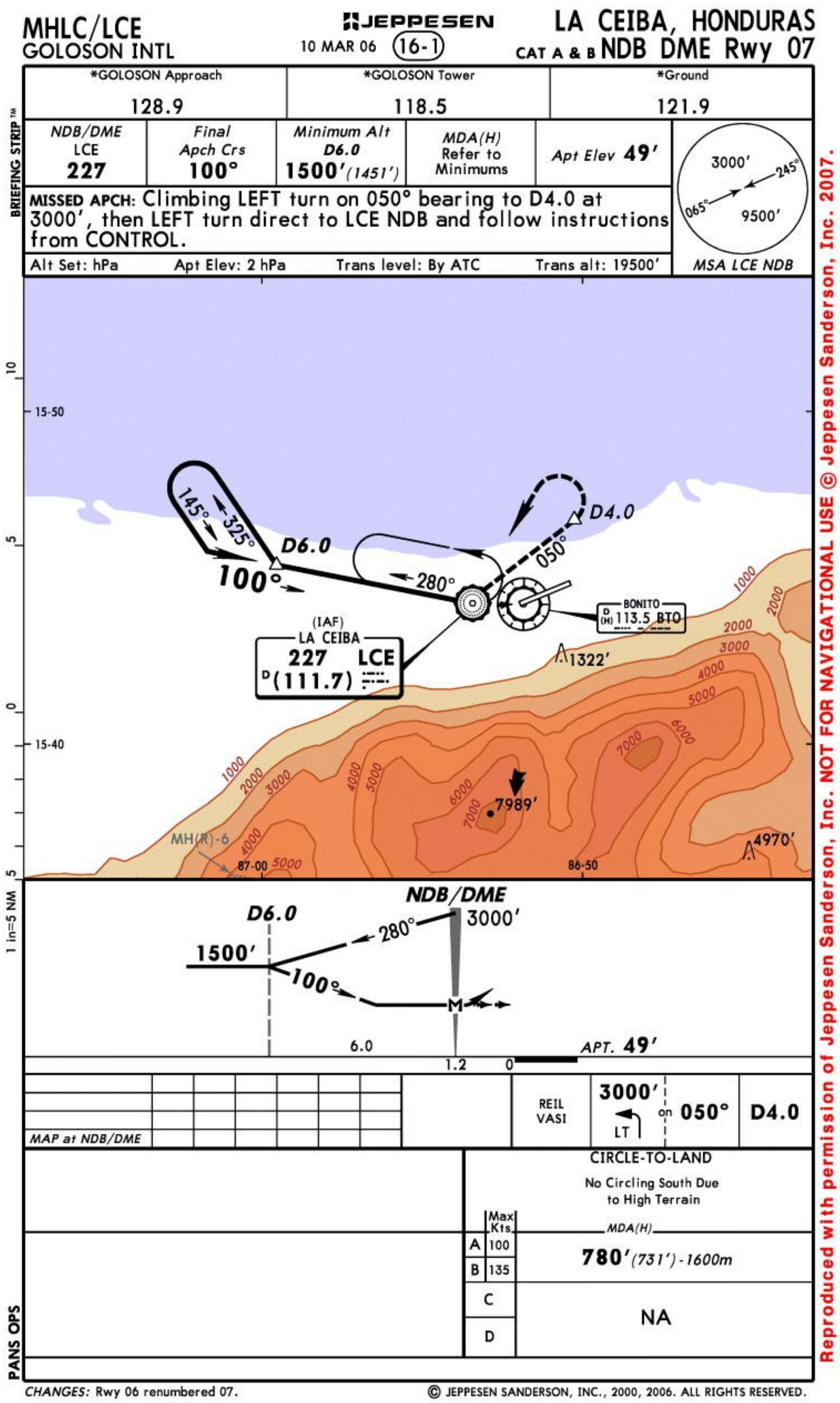


Figure 3

La Ceiba – NDB DME Rwy 07

- The availability of a DME, as part of the reference navaid (e.g., VOR DME), or of a system providing the aircraft distance to the runway threshold (e.g., an area navigation computer) significantly enhances the capability of the pilot to localize the aircraft position along the lateral path of the final approach.

  Furthermore, the distance information allows to better materialize the intended vertical flight path of the final approach (i.e., through altitude-distance checks).

- The non precision nature of the approach is also caused by the poor materialization of the vertical path of the final approach. This materialization is very partial and quite discontinuous, since it may be as poor as being provided only by an assigned altitude at the FAF and by the distance from the FAF to the MAP.

  Thus, the crew awareness of the aircraft vertical position versus the intended vertical path of the final approach is quite low.

The RNAV Approaches of the Eighties

These approaches are point-to-point trajectories. Each point may be defined either by a bearing / distance to a reference ground navaid (VOR – DME) or – as this is the case today – by a geographic position defined as a latitude / longitude. Each point is assigned a passing altitude.

Consequently, RNAV approaches clearly define both a lateral and a vertical trajectory, that the aircraft must fly on final.

Some RNAV approaches are defined as an overlay to existing approaches; the geographic trajectories are therefore the same.

Most RNAV approaches are straight-in approaches; however, some of them are constituted by a succession of non-aligned straight segments (these approaches are known as segmented approaches).

In order to fly such RNAV approaches, an adequate aircraft equipment is required (as set forth in the applicable approach chart).

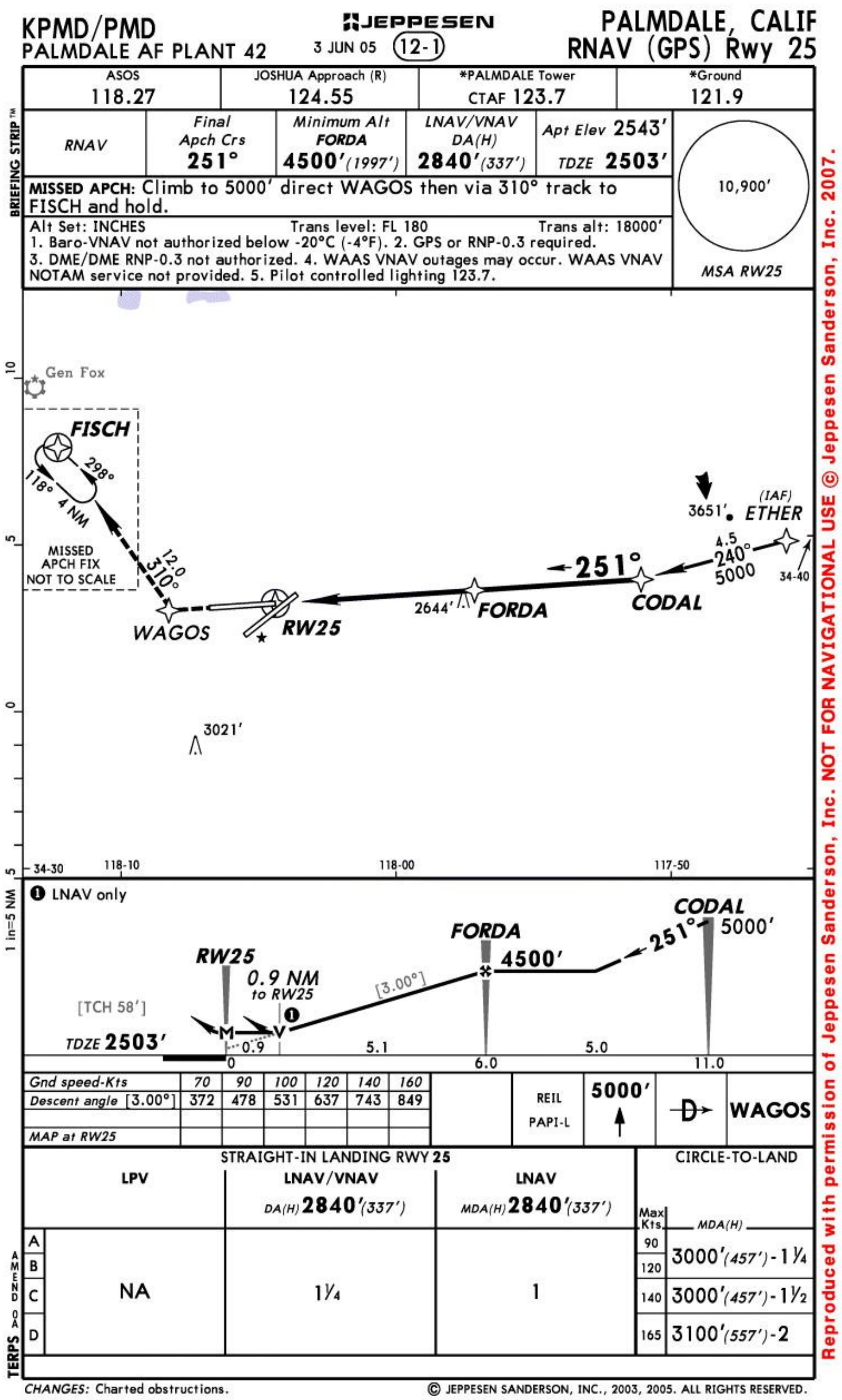


Figure 4

Palmdale – RNAV (GPS) Rwy 25

The RNP RNAV Approaches from the Nineties, Onwards

The RNP RNAV approaches are basically defined as RNAV approaches within a performance-based navigation (PBN) concept.

This concept means that the aircraft is able to fly the RNAV approach trajectory and to match a required navigation performance (RNP), e.g. RNP 0.15 nm; thus, the aircraft navigation system has to monitor its actual navigation performance (ANP) – typically the total navigation error : The system and flight technical error – and has to identify whether the RNP is actually met or not during the approach.

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

In order to fly such RNP RNAV approaches, an adequate aircraft equipment is required (as specified on the applicable approach chart, refer to **Figures 5** and **6**).

This concept gives a great flexibility to approach designers; indeed, the notion of containment allows them to consider approach trajectories which can satisfy various potential conflicting constraints such as terrain, noise, environment, prohibited areas, …, while ensuring a comfortable, flyable, constant descent-angle vertical path, with approach minima's dictated by RNP (as illustrated in **Figure 5**).

The 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. The approach vertical path is a constant-angle path.

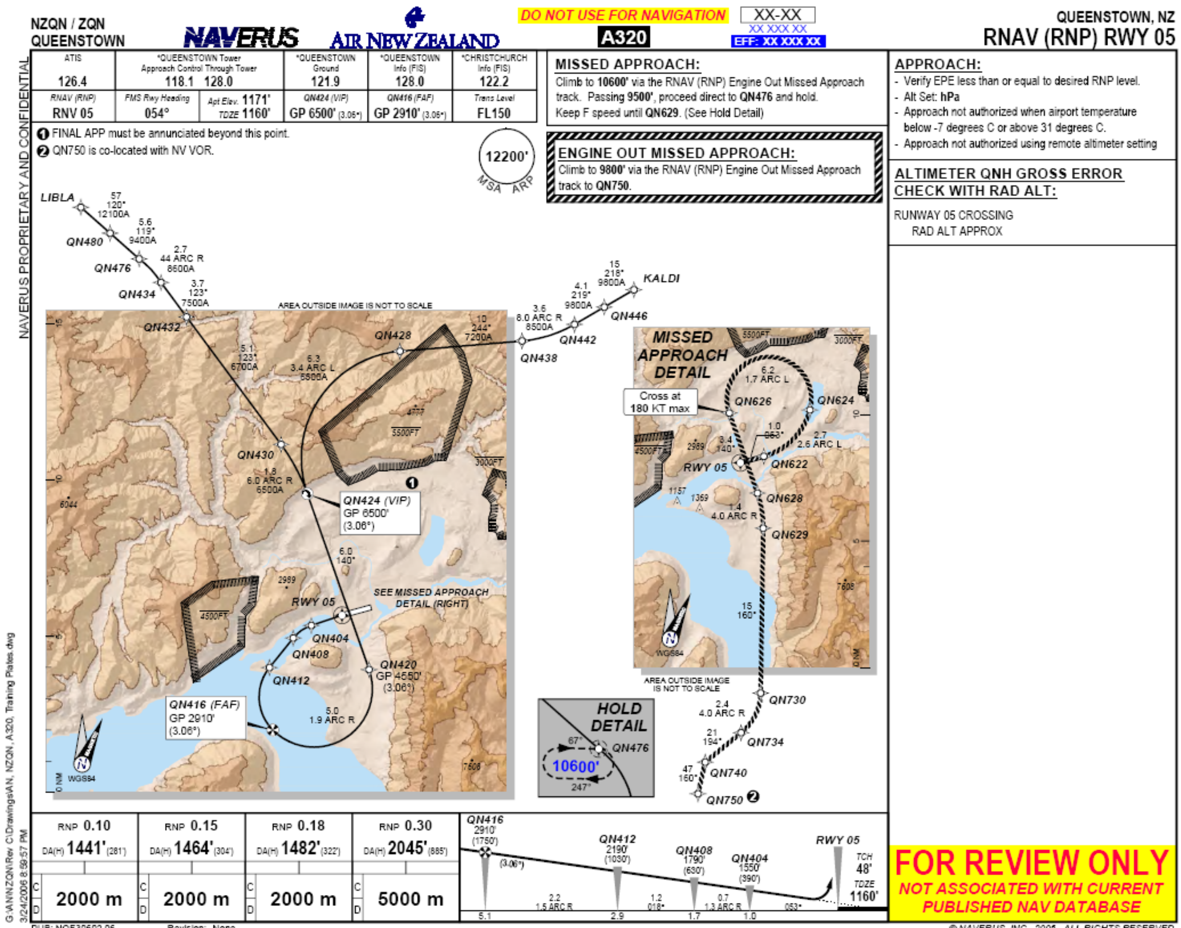


Photo Credit: Naverus

Figure 5

Queenstown – RNAV (RNP) Rwy 23 – Approach Minimas vs RNP

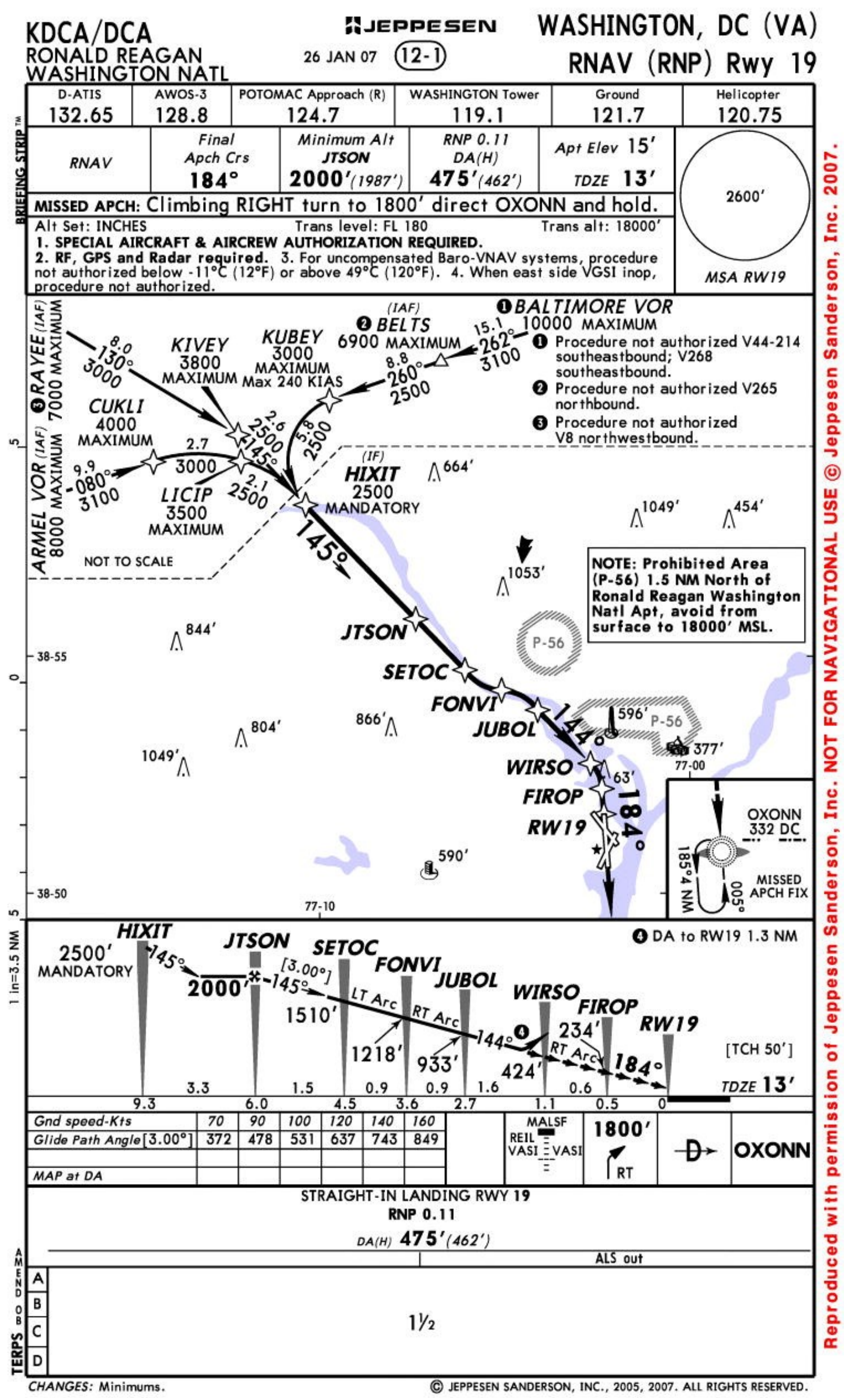


Figure 6

Segmented / Curved Approach
Washington - DCA – SAAAR RNAV (RNP) Rwy 19

II.2 The On-board Equipment

The methods and procedures recommended to fly non-ILS approaches obviously depend upon the cockpit systems and the onboard equipment, to ensure the following functionalities:

- Navigation;
- Guidance; and,
- Display.

Navigation Functionalities

The navigation functionalities are those which provide the pilot with the best estimation of the aircraft position and its deviation versus an intended flight path.

- **First step: the seventies**

  Navigation functionalities were essentially based on radio navigation receivers which received signals from ground based navaids such as ADF, VOR, LLZ, DME, … .

  Some aircraft were also equipped with an inertial navigation system (INS) which could be updated by specific navaids; for long range flights, systems like the LORAN, omega navigation system (ONS) and area-navigation (RNAV) computers were also used.

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

- **Second step: the eighties**

  Two major steps forward have been made in navigation functionalities in this period, the wide spread use of inertial reference systems (IRS) and the adoption of the flight management system (FMS).

  – Most commercial aircrafts got equipped with at least one IRS, which processed the aircraft position autonomously and permanently with a decent performance level; and,

  – The aircrafts got also equipped with at least one FMS which processed permanently the aircraft position and ensured flight navigation functions.

    The FMS used all IRS positions available, averaged these positions into a MIX IRS position which was then updated using the best pair of DME's within reach, or using a VOR – DME within reach.

    Consequently, the FMS could provide a good aircraft position, along with an estimate of its accuracy.

    The FMS achieved lateral and vertical flight planning functions, which means that it could string together all the legs of a flight plan (F-PLN); amongst others, all the legs constituting the approach.

The FMS is able to assign passing altitudes at various waypoints of the approach as well as a descent angle for certain legs; amongst others, the final approach legs.

As a result, the FMS processes the aircraft position, an estimate of its accuracy and the deviations which may exist in between the aircraft position and the lateral / vertical intended F-PLN.

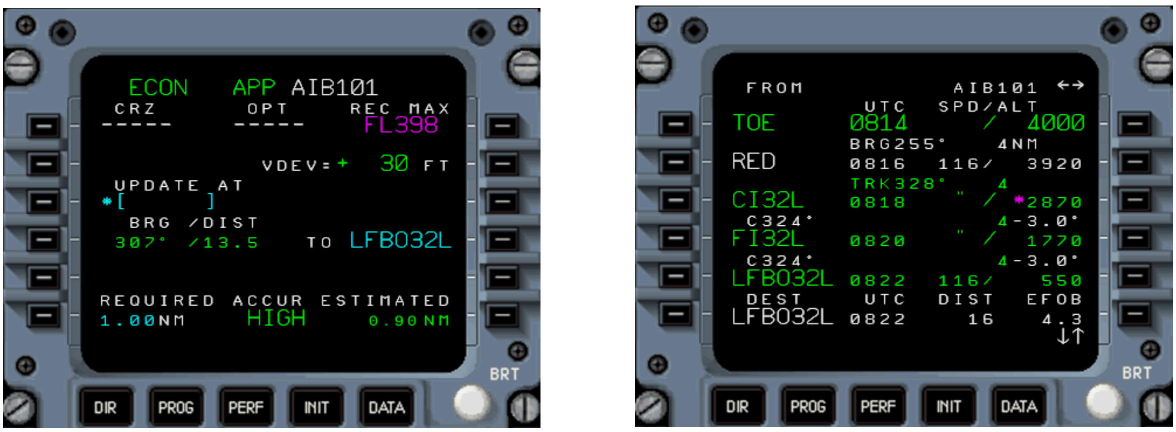


Figure 7

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

- **Third step: from the nineties onwards**

  The major step forward in that period has been the coming of the GPS:

  – First, because of its remarkable accuracy;

  – Second, because of its capability to properly estimate its performance;

  – Third, because of its quasi-worldwide and quasi-permanent availability; and,

  – Fourth, because of its capability to monitor its integrity.

  The GPS is therefore used as a primary navigation sensor by the FMS which outputs also the navigation performance (estimated error or actual navigation performance – ANP).

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

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

  – RNP values assigned to approach legs, for example, may be set in the database;

– All flight plan legs are geographically defined (i.e., referenced to earth) and fixed radius turns (RF leg) are provided between two legs, making these turns also geographic trajectories.

Note :

The importance of defining "geographic" legs will be illustrated further when discussing the design of curved RNP RNAV approaches in a mountainous environment.

– Whenever required, the descent-angle assigned to a leg (e.g., in approach) is also set in the FMS database, for a better determination of the approach profile.

Figure 8

Airbus FMS PROG Page with GPS PRIMARY – DATA POS MON Page – Typical

Guidance Functionalities

The guidance functionalities are those which are used by the pilot to fly the aircraft in approach.

- **First step: the seventies**

  In IMC, the pilot used the conventional attitude indicator (ADI) and horizontal situation indicator (HSI) as reference to fly the aircraft. In order to control a descent (climb) gradient, he/she used the vertical speed indicator (VSI) as well as the altimeter.

  Most commercial aircrafts 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,

– NAV, in case an INS or an area-navigation computer was installed.

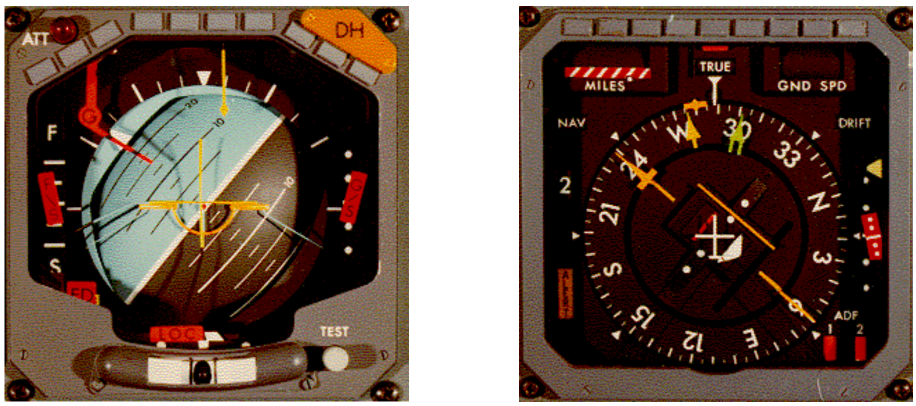


Figure 9

A300B4 ADI and HIS (1972 – 1982)

- **Second step: the eighties**

  Two major steps forward have been made in guidance functionalities in that period:

  – The introduction of glass-cockpits that allowed to replace conventional ADI's by the Primary Flight Display (PFD), part of the Electronic Flight Instrument System (EFIS), featuring new flying cues such as the Flight Path Vector (FPV).

  The FPV materializes the instantaneous flight path angle (FPA) and track (TRK) flown by the aircraft, hence its instantaneous trajectory.

  The FPV assists the pilot to fly and control 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 of the FPV has allowed to provide additional AP / FD modes best adapted to tracking a trajectory:

    - FPV associated modes (**Figure 10**):

      - TRK and / or FPA: basic modes associated with the use of the FPV.

    - FMS associated modes (**Figure 11**):

      - NAV (or LNAV), ensuring the guidance of the aircraft along the lateral F-PLN; and,

      - DES and FINAL APP (or VNAV), ensuring the guidance of the aircraft along the vertical F-PLN.

FINAL APP (or LNAV/VNAV) is combined mode that guide the aircraft along non-ILS approaches, both laterally and vertically.

Figure 10

Airbus PFD illustrating FPV / FPD and TRK - FPA modes

Figure 11

Airbus PFD illustrating FPV / FPD and FMS FINAL APP mode

- **Third step : from the nineties onwards**

  The guidance functionalities have been affected by the spread of the head-up display (HUD) in the cockpits, as well as by the enhancement of the FMS associated modes:

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

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

  Consequently, the AP/FD modes associated to the FMS are now able to guide the aircraft on any type of non-ILS approach, both laterally and vertically, with great precision, and thus match the 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 G/S (F-G/S) modes of the Airbus FMS Landing System (FLS).

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 data base.

Consequently, when flying such straight-in approaches with IAN / FLS modes, the procedures to intercept and track the FLS virtual beam are most similar to the procedures used for an ILS.

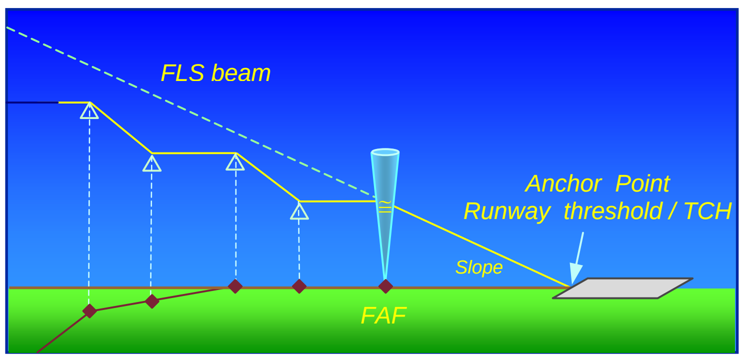


Figure 12

FLS – Virtual Beam - Anchor Point

Display Functionalities

The display functionalities are those which provide the crew with the information required to adequately monitor the achievement of the non-ILS approach.

- **First step: the seventies**

  The essential information provided in that period was the position of the aircraft relative to the intended lateral trajectory of the approach, e.g., the aircraft current radial to the reference navaid, versus the approach intended radial.

  This information was provided on DRMI's (for NDB and VOR approaches) and on the HSI (for VOR, LLZ, … approaches), which materialized the deviation between the current and intended approach radial.

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

The crew awareness regarding the aircraft vertical position versus the intended vertical path was very poor. Several pieces of information allowed the crew to estimate this aircraft position:

- The vertical speed indicator (VSI);
- The altimeter;
- The chronometer; and,
- The DME.

Figure 13

The Seventies – HIS - DRMI

- **Second step: the eighties**

The major step forward in display functionalities in that period was the glass-cockpit with the Electronic Flight Instrument System (EFIS) displays : Primary Flight Display (PFD) and Navigation Display (ND), the ND being directly linked to the FMS.

The FMS linked to the ND has somehow solved the orientation problems some pilots had with the DRMI or HSI.

The ND is therefore used to display:

- The aircraft lateral position relative to the intended lateral path, namely the FMS F-PLN; amongst others, the final approach trajectory;
- The cross-track error (XTK);
- The VOR or ADF needles, as reference navaids raw data; and,
- The DME distance.

The PFD is used to display the vertical deviation (V/DEV) from the intended final approach descent path, as defined / selected in the FMS.

Figure 14

Airbus – EFIS PFD – FINAL APP mode – V/DEV shown

- **Third step: from the nineties onwards**

  The display functionalities have been somehow enhanced in that period, using the PFD and ND as basis. This enhancement has been dictated by the tremendous increase in navigation performance provided by the GPS, which has allowed to extend the operational capabilities of the aircrafts: reduction of aircraft separations, reduction of approach minima's …, amongst others.

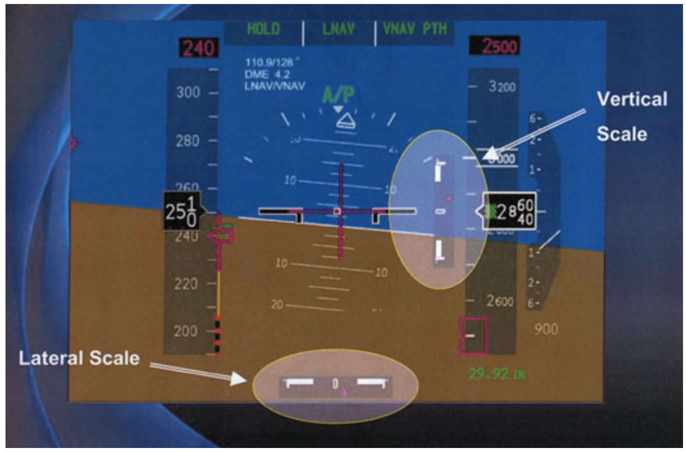
  Consequently, most non-ILS approaches can now be flown as precision-like approaches, provided adapted piece of information are displayed for crew situational awareness. Furthermore, the development of the required navigation performance (RNP) concept has led to specific requirement in terms of monitoring.

  The evolutions of display functionalities may be summarized as follows :

  – On PFD, lateral deviation scales tailored to RNP requirements;

  – On PFD and ND, displays adapted to IAN or FLS modes, as described earlier;

  – Vertical situation display (VD) added at the bottom of the ND, for enhanced vertical situational awareness.



(Photos Credit : Boeing Commercial Airplanes)

Figure 15

Boeing - EFIS PFD – RNP Scales

Figure 16

Airbus EFIS PFD – FINAL APP mode – RNP Scales (V/DEV – L/DEV shown)

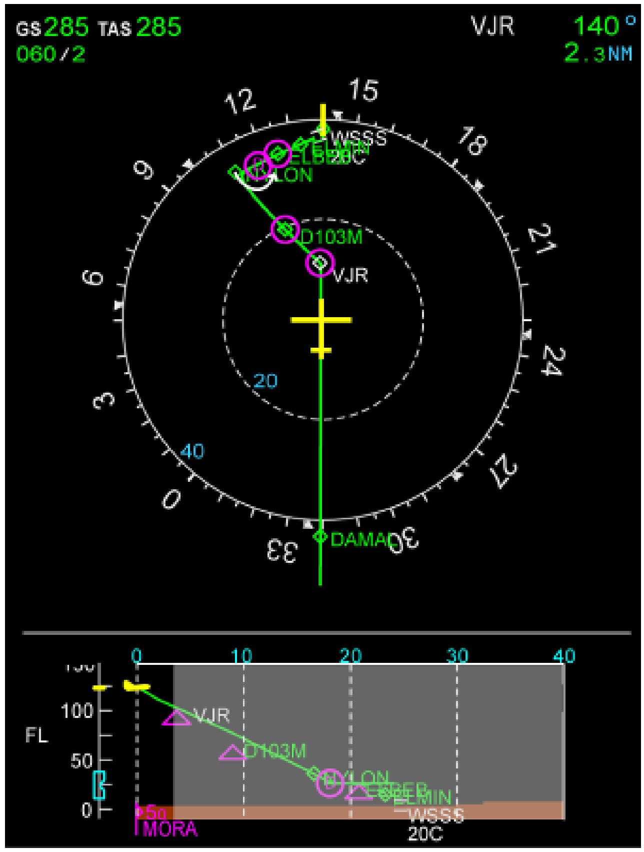


Figure 17

Airbus A380 - EFIS ND – Vertical Situation Display (VD)

III Methods and Procedures

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

- The nature of the non-ILS approach, from the traditional NPA's of the seventies to the RNP RNAV approaches of today; and,

- The on-board equipment, from the ADI / HSI / DRMI and very basic AP / FD modes of the seventies to the current glass cockpits with FMS / GPS and LNAV / VNAV capable AP / FDs.

Additional factors associated to the nature of the approach affect those procedures:

- 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 the procedure turn of a teardrop approach, for example;

- The position of the MAP, which defines the end point of the final approach at which a go-around should be commanded by the pilot, at the latest. The MAP may be located at the runway threshold, before or beyond the runway threshold;

- The nature of the minima's, MDA(H) or DA(H):

  The MDA(H) being a minimum descent altitude, no altitude loss below the MDA(H) is allowed during the approach and go-around; this implies to either:

  – Level-off at the MDA(H) - step-down / dive-and-drive technique - until visual references are acquired:

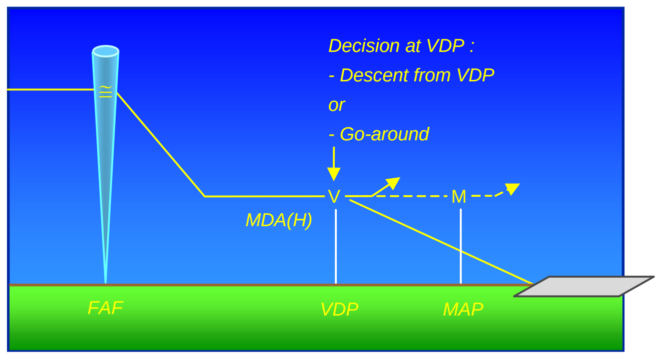


Figure 18

Go-around Decision – Step-down NPA

  – Initiate the go-around above the MDA(H) - constant descent-angle technique - if no visual references are acquired, in order not to "duck under" the MDA(H).

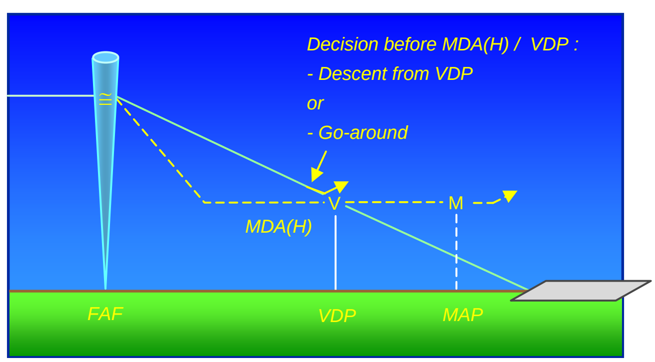


Figure 19

Go-around Decision – Constant Descent Angle NPA – With MDA(H)

This is obviously not required when the applicable minima is a DA(H), which is a decision altitude; if no visual references are acquired when reaching the DA(H), a go-around must be initiated at DA(H) as illustrated by **Figure 22** and by the approach chart in **Figure 6**.

Considering all those factors, let us review the evolutions of the non-ILS approach procedures in the three steps in time considered in this Flight Operations Briefing Note.

III.1 First step : the seventies

The non-ILS approaches in that period were the traditional NPA's using a NDB, VOR or LLZ – and, possibly, a DME – as reference navaid(s), whereas the onboard equipment was quite conventional in terms of navigation, guidance and display functionalities.

Two types of methods and procedures were recommended which actually affected the control of the vertical flight path of the aircraft, whereas the control of the lateral flight path was common to both types.

Most airframe manufacturers did recommend the use of the autopilot for lateral and vertical control of the aircraft during the approach.

Lateral Path Control Procedure

The control of the lateral flight path of the aircraft called for a unique method:

- Tune reference navaids for the approach;
- On DRMI, set switch to ADF (VOR) for an NDB (VOR) approach;
- Set EHSI switch to VOR (ILS) for a VOR (LOC-only) approach;
- Set the final approach course as CRS target for the EHSI;
- Use autopilot roll / lateral modes as follows:
  - HDG mode for an NDB approach, as well as during intermediate approach;
  - VOR (LOC) for a VOR (LOC-only) approach;
- Disengage the autopilot once visual references are acquired, at MDA at the latest, in order to complete the approach visually and manually.
- Monitor the lateral trajectory of the aircraft using raw data on the EHSI or DRMI.

Vertical Path Control Procedures

The control of the vertical path of the aircraft used two different methods and procedures; both methods assumed that the aircraft was flying in landing configuration, at the final approach speed (V APP), from the FAF down to the landing or to the initiation of a go-around:

- **The traditional "step-down" / "dive-and-drive" method:**

  This is illustrated by **Figure 15**, below:

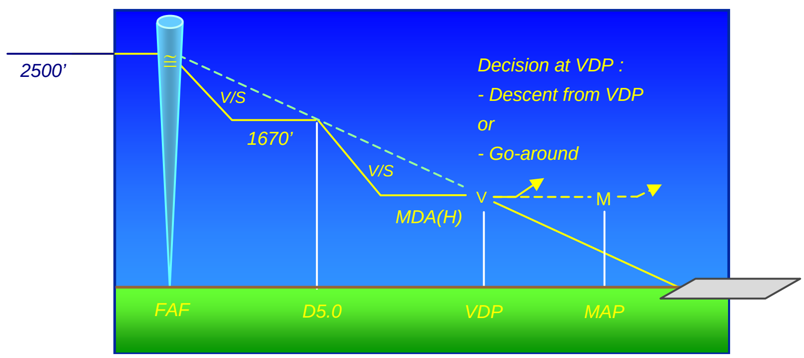


Figure 20

Step-down / Dive-and-drive Approach Method - Typical

For non-FMS / non-glass-cockpit aircrafts that used NDB / VOR / DME / LOC (ILS LLZ) raw data for approaches, the traditional dive-and-drive method was therefore recommended down to MDA(H). However, a provision for recommending the use of a constant descent-angle, as a function of the aircraft estimated ground-speed, had been added, provided a corresponding table was available on the approach chart.

The recommended procedure to fly down the NPA was as follows:

- Select V/S – 1000 ft/mn at the FAF (up to – 1500 ft/mn, when above 1000 ft AGL), even if a level flight segment is depicted after the FAF on the chart;
- Level off at next step-down altitude(s); monitor and callout DME / altitude check(s), if available;
- Select V/S – 1000 ft for flying the last step-down to the MDA(H); and,
- If the airfield is not in sight at an altitude equal to MDA(H) + 10 % of the descent rate (e.g., 100 ft for a typical – 1000 ft/mn rate of descent, so typically at MDA(H) + 100 ft), V/S must be reduced to ensure that the aircraft does not descend below the published MDA(H); this may result in reaching minimums past the published or calculated visual descent point (VDP).

Note :
*The VDP is either depicted on the charts as a V (as illustrated in **Figure 20**) or estimated by the pilot. The VDP is located along the final approach trajectory at a distance from the runway threshold which allows a –5% (-3°) descent path to the runway, when passing the VDP at MDA(H).*

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

This method was promoted in all cases of NPA's by certain operators, who flew many NDB approaches without DME and without published vertical descent angle or rate of descent, so as to have a unique procedure for all non-ILS approaches they flew.

However, this traditional step-down approach technique had the following drawbacks:

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

– The aircraft reached MDA(H) in quasi-level flight:
  - either before the VDP; or,
  - after the VDP.

  Consequently, the acquisition of visual references was affected by the pitch attitude of the aircraft that was significantly greater than the nominal pitch attitude observed when the aircraft is established on a - 5 % / - 3 ° approach descent angle; this affected the perspective view of the runway. Furthermore, when acquiring visual references beyond the VDP, the pilot was tempted to continue visually the final approach, which often resulted in a high-descent-rate during the visual segment before landing.

The technique led to unstabilized approaches which, as line experience showed, led to off-runway touchdown (e.g., land-short), runway excursions / overruns or tail-strikes.

Kathmandu VOR DME approach to Rwy 02 :

The above discussion is well illustrated by the VOR DME approach into Kathmandu runway 02, the following can be observed:

– The Kathmandu VOR DME approach for runway 02 is a challenging multi-step-down approach, as illustrated on **Figure 21**;

– Until recently, most operators flew this approach using the traditional step-down procedure; and,

– During most of the approach, the aircraft is not stabilized; this has been the cause of a number of CFIT events and approach-and-landing incidents / accidents.

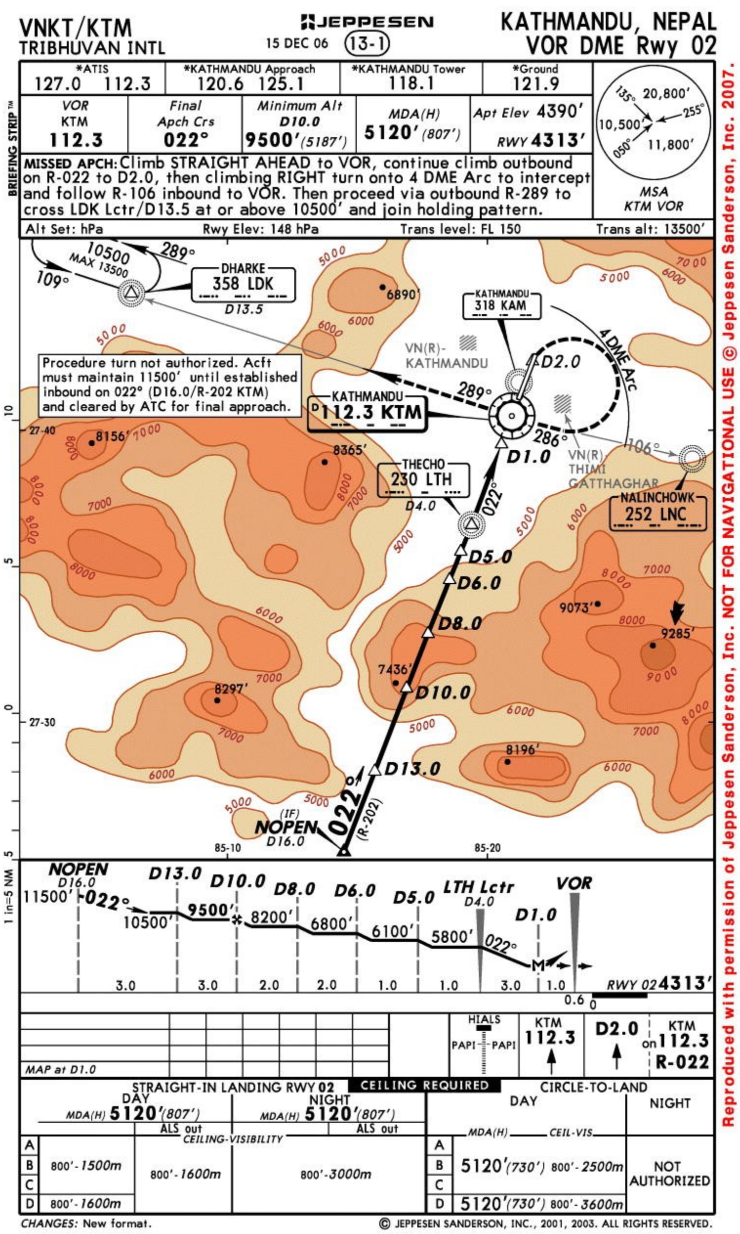


Figure 21

Kathmandu – VOR DME Rwy 02 – Multi-step-down Approach)

- **The Constant-angle Approach Method:**

The principle of this method is as follows:

The crew computes the adequate V/S to fly from the FAF to the VDP, on a constant-angle path. This adequate V/S is a function of the average ground speed of the aircraft during the approach.

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

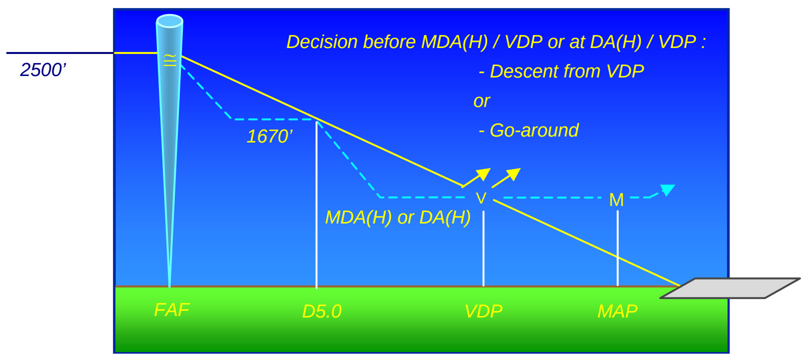


Figure 22

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

Consequently, during the intermediate approach at the latest, the pilot:

– Assesses the average ground speed estimated 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 FCU (MCP), with the V/S target previously determined (for aircraft models not featuring a V/S mode, the pitch mode is used and the pitch attitude adjusted to obtain the desired V/S); and,

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

No descent below MDA(H) is allowed if visual references are not acquired; a go-around must be immediately initiated.

No level-off at MDA(H) should be considered, as delaying the go-around decision until the MAP would not allow – with most published MAP positions – to complete a stabilized visual segment and landing.

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

- The aircraft is flying stable during the final approach: 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 assess 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.

III.2 Second step: the eighties

The non-ILS approaches were traditional NPA's as well as RNAV approaches, in that period.

The onboard equipment had been upgraded with :

- Glass-cockpits, featuring an EFIS (PFD, ND, …);
- FMS with high-performance aircraft position computation (MIX IRS position enhanced by DME / DME or VOR / DME corrections); and,
- AP / FD with basic TRK / FPA modes and FINAP APP (or LNAV / VNAV) combined modes.

All these systems did favor the concept of trajectory; the basic TRK / FPA modes, the display of the FPV on the PFD and – obviously – the flight planning capabilities of the FMS.

Consequently, lateral and vertical guidance, referenced from the FMS position, could be provided along a trajectory retrieved from the FMS navigation data base, such as non-ILS approaches.

The AP / FD LNAV / VNAV (FINAL APP) mode could track this approach trajectory, thus ensuring that the cross-track distance (XTK or L/DEV) and the vertical deviation (V/DEV) were kept to zero.

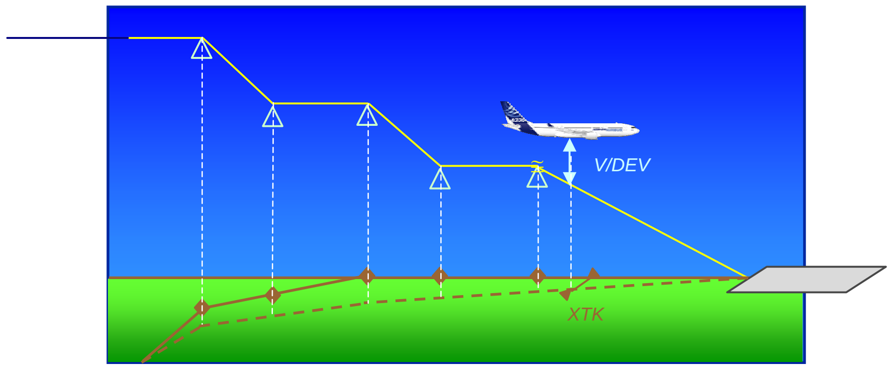


Figure 23

Lateral Trajectory – XTK – L/DEV

Vertical Trajectory – V/DEV

What were the procedures and methods used by operators in that period?

Some operators did still recommend the traditional step-down method. However, they were taking benefit of the FMS lateral navigation (NAV or LNAV modes) and used the EFIS ND ARC or MAP display mode, which provided the aircraft instantaneous position versus 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 using fully the FMS:

- As first precaution, 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).

  The FMS position accuracy actually dictated the strategy which would be used for the completion of the approach, regarding:

  - The AP / FD modes selected to fly the approach; and,
  - The ND display mode selected to monitor the approach.

  If the FMS navigation accuracy was checked 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 the FMS navigation accuracy was not within the applicable tolerances:

- The AP / FD TRK / FPA modes had to be used to track the lateral and vertical trajectory of the non-ILS approach; and,
- The EFIS ND ROSE VOR (ILS) – EHSI-type - display mode had to be used on the PF side at least; PNF 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 renders the EFIS ND MAP display most misleading.

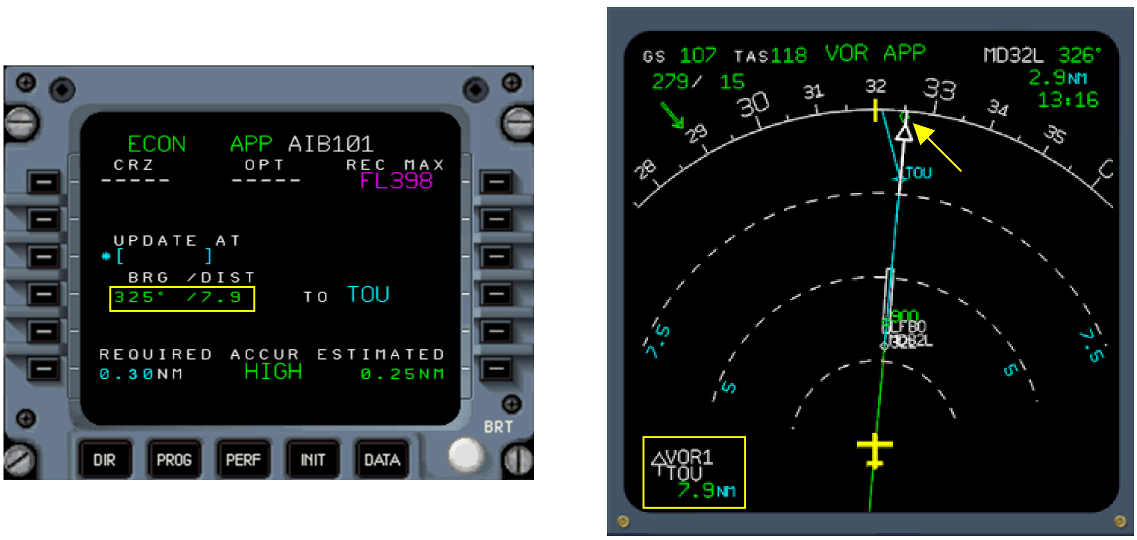


Figure 24

FMS Navigation Accuracy Check

Airbus - FMS PROG Page – ND with ARC Display Mode

- As a second precaution, the pilot had to check the quality of the FMS navigation data base, in order to ensure that the final approach inserted in the FMS F-FLN by the pilot was correct.

  The final approach could not be modified by the crew, 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 passing altitudes and the flight-path angle of the various legs provided on the FMS MCDU - RTE LEGS or F-PLN page were consistent with the published procedure.

If those two precautions were satisfied, then the FMS, its associated guidance modes and display functionalities might be used for the final approach completion, which was the preferred technique.

On certain aircrafts, the FPV was provided on the EFIS PFD as flying reference: The FPV was to be selected during non-ILS approaches because it was the best adapted flying reference to fly 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 the final approach, as inserted on the FMS MCDU, versus the published procedure;
  - Select FPV as flying reference (if available); and,
  - Check the DA on the FMA, as inserted in the FMS.

- Intermediate approach:
  - Decelerate and configure the aircraft in the landing configuration;
  - Intercept the final approach radial:
    - If ATC clears the aircraft along the FMS F-PLN, use the NAV mode;
    - If ATC gives radar vectors, use HDG (TRK) mode and the DIR TO [...] INTCPT RADIAL INBOUND or COURSE on FMS;
  - Monitor the interception, using the ND in ARC or MAP display mode; and,
  - When ATC clears the aircraft to intercept the final approach, press the APPR pushbutton of the FCU (or arm the NAV / LNAV mode on the MCP).

- Final approach:
  - Ensure that the aircraft is established in landing configuration at V_{APP} prior to the FAF;
    - Reaching the FAF, check that FINAL APP (LNAV / VNAV) engages (or select VNAV, as applicable);
  - Set missed-approach altitude on FCU (MCP);
  - Monitor that the aircraft is properly guided along the FMS final approach:
    - Using the ND in ARC or MAP display modes;
    - Using the V/DEV on the PFD.
  - 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 go-around; there is no level flight at DA(H).

***Note 1*:**

In certain cases, the final approach is not properly coded in the database regarding the vertical path, 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.

***Note 2*:**

Published MDA(H)'s may be used as DA(H)'s according to local regulations, provided VNAV or an equivalent mode (FINAL APP) is used on final approach.

The various steps of the constant descent-angle approach technique can be summarized and illustrated on the following perspective view of a typical approach:

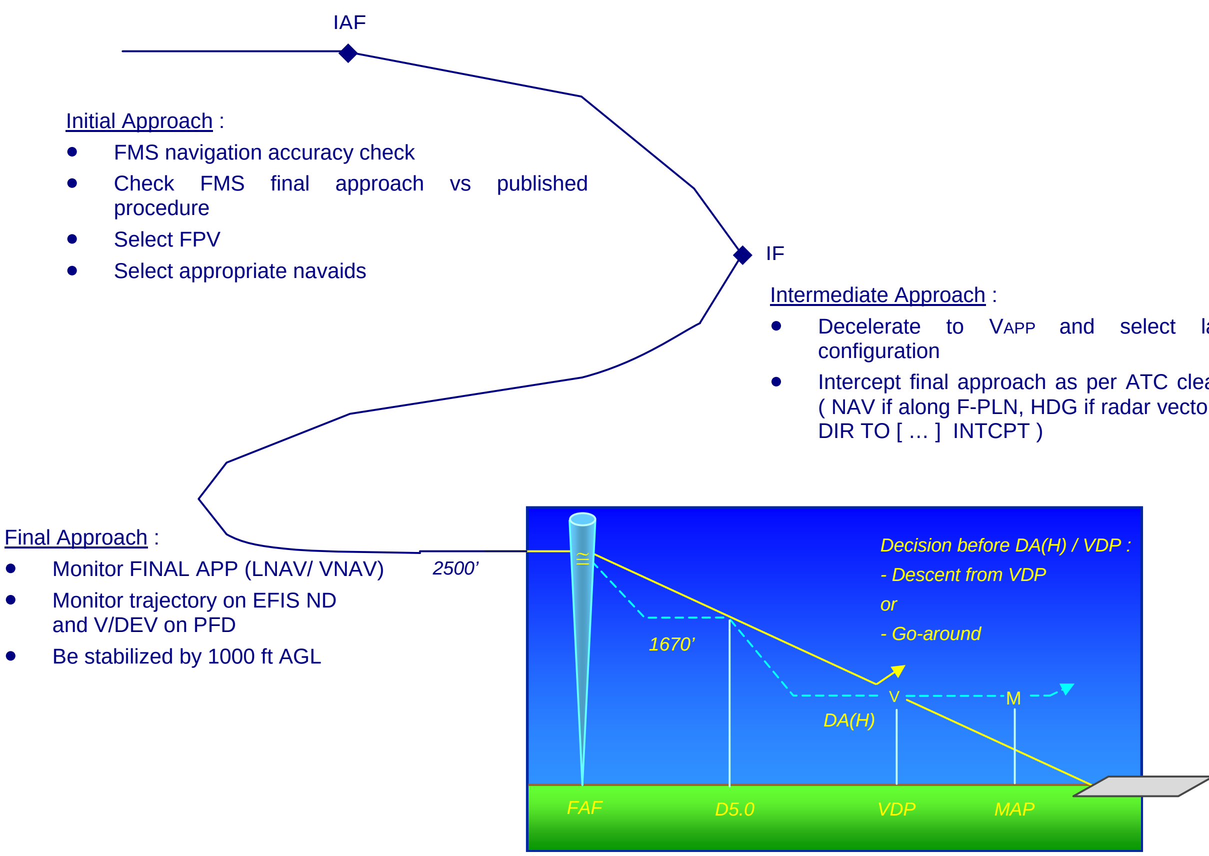


Figure 25

Constant-angle Descent Approach Technique – Synthesis

Summary of the method promoted in the eighties

The methods and procedures recommended by manufacturers to fly non-ILS approaches, in that period, may be summarized by:

- Fly stabilized approaches; and,
- Fly constant descent-angle approaches.

What are the advantages of those techniques?

- Stabilized approach means that the aircraft is on the proper lateral / vertical path, with landing configuration and final approach speed, thus with adequate thrust setting and pitch trim, thus enhancing:
  - Pilot horizontal and vertical situation awareness;
  - Pilot speed awareness; and,
  - Pilot energy awareness, with thrust being maintained close to the level required to fly the final approach descent path at the final approach speed.
- The constant descent-angle approach:
  - Ensures an approach profile which offers a greater obstacle clearance along the final approach course;
  - Offers an approach technique and procedure similar to the ILS technique, including the go-around and missed-approach;
  - Significantly reduces pilot's workload during final approach, which enhances pilot's situational awareness;
  - Ensures an adequate aircraft pitch attitude that facilitates the acquisition of visual references when approaching DA(H); and,
  - Additionally, is more fuel efficient and reduces noise level for nearby communities.

Consequently, it can be stated that the non-ILS approaches (traditional NPA's and RNAV approaches) are flown as ILS-alike approaches, due to the stabilized / constant descent-angle technique, provided by an appropriate procedure and guidance modes (LNAV / VNAV or NAV / FPA) which involves the use of a DA(H) instead of a MDA(H).

Kathmandu VOR DME approach to Rwy 02:

In the eighties, this approach was still being flown using the step-down / dive-and-drive technique, with multi-step-downs; which had caused several CFIT accidents.

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

- From NOPEN (as FAF) to D10.0: - 3.1 ° constant-angle descent segment;
- From D10.0 ……………… to D5.0: - 6.11 ° constant-angle descent segment; and,
- From D5.0 …………….. … to MAP: - 3.17 ° constant-angle descent segment.

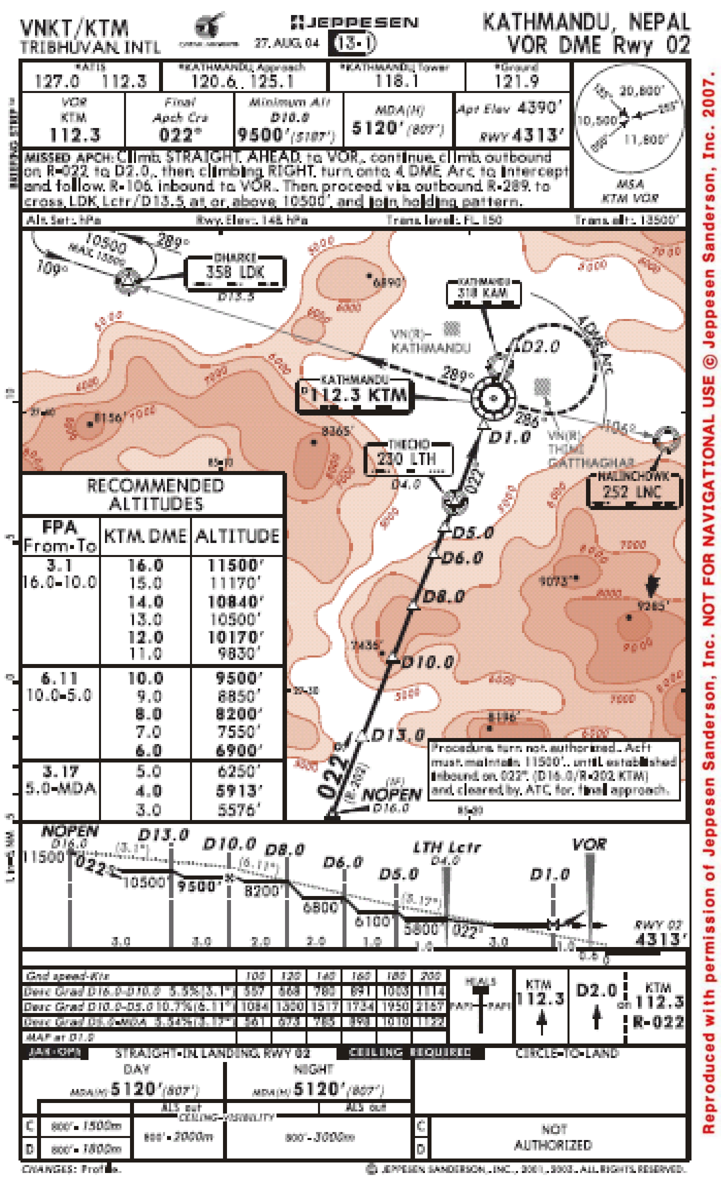


Figure 26

Kathmandu – VOR DME Rwy 02 – Constant-angle Descent Segments

AIRBUS

Most VNAV modes are performing down to descent angles as steep as - 4.5 °. Consequently, those operators now fly the Kathmandu final approach using the NAV / FPA modes, with landing configuration and V_{APP} stabilized before NOPEN:

- At 0.2 nm from NOPEN, FPA is set to – 3.1 ° on FCU (MCP);
- At 0.2 nm from D10.0, FPA is set to – 6.1 ° (speedbrakes are extended due to the higher descent angle); and,
- At 0.2 nm from D5.0, FPA is set to – 3.2 ° (speedbrakes are retracted).

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

III.3 Third step : from the nineties onwards:

The coming of the GPS, with its extremely high navigation performance and integrity-monitoring capability, has really affected the way non-ILS approaches are being flown and has allowed to fully implement the RNP (required navigation performance / containment) concept.

Furthermore, the enhancement of display functionalities (e.g., vertical situation display – VD) and of guidance functionalities (e.g., LNAV, VNAV enhancement, FLS, IAN, HUD, …) has further reinforced the stabilized / constant-angle final approach technique.

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

What are the flying techniques and methods recommended today?

Two methods / flying techniques are recommended depending upon the geometry of the approach and aircraft equipment:

Flying Technique Using FINAL APP (LNAV / VNAV) AP Guidance Modes

This flying technique is applicable to all types of non-ILS approaches (i.e., traditional NPA's, RNAV and RNP RNAV approaches) straight-in, segmented or curved, properly coded in the FMS navigation data base.

The procedure is similar to the one provided in the section "**Second step: the eighties**":

- Same precautions must be taken regarding checking the FMS navigation accuracy; however, since the GPS is able to monitor its performance and integrity, some alerts automatically advise the crew when / if :
  - The navigation performance is not satisfactory;
  - The GPS PRIMARY capability is lost; or,
  - The RNP level is not satisfied.

- Same precautions must be taken regarding checking the proper coding of the final approach in the FMS navigation data base; and,
- Same flying technique applies.

Figure 27

Airbus EFIS PFD with RNP Deviation Scales

However, three remarks must be mentioned :

- If an RNP RNAV approach is flown, the deviations provided on the EFIS PFD are scaled to the RNP; and,
- Since Baro-VNAV is used and guides the aircraft on the flight path angle provided by the FMS, assuming a standard-atmosphere, if the OAT is significantly lower / higher than standard, the baro VNAV guidance will guide the aircraft on a more shallow / steeper flight path than expected.

  This explains why, on approach charts, a minimum OAT is specified to operate with VNAV, in order to maintain the required minimum obstacle clearance.

  A maximum OAT may also be provided.
- Those approaches are flown down to DA(H) or MDA(H) depending on local regulations.

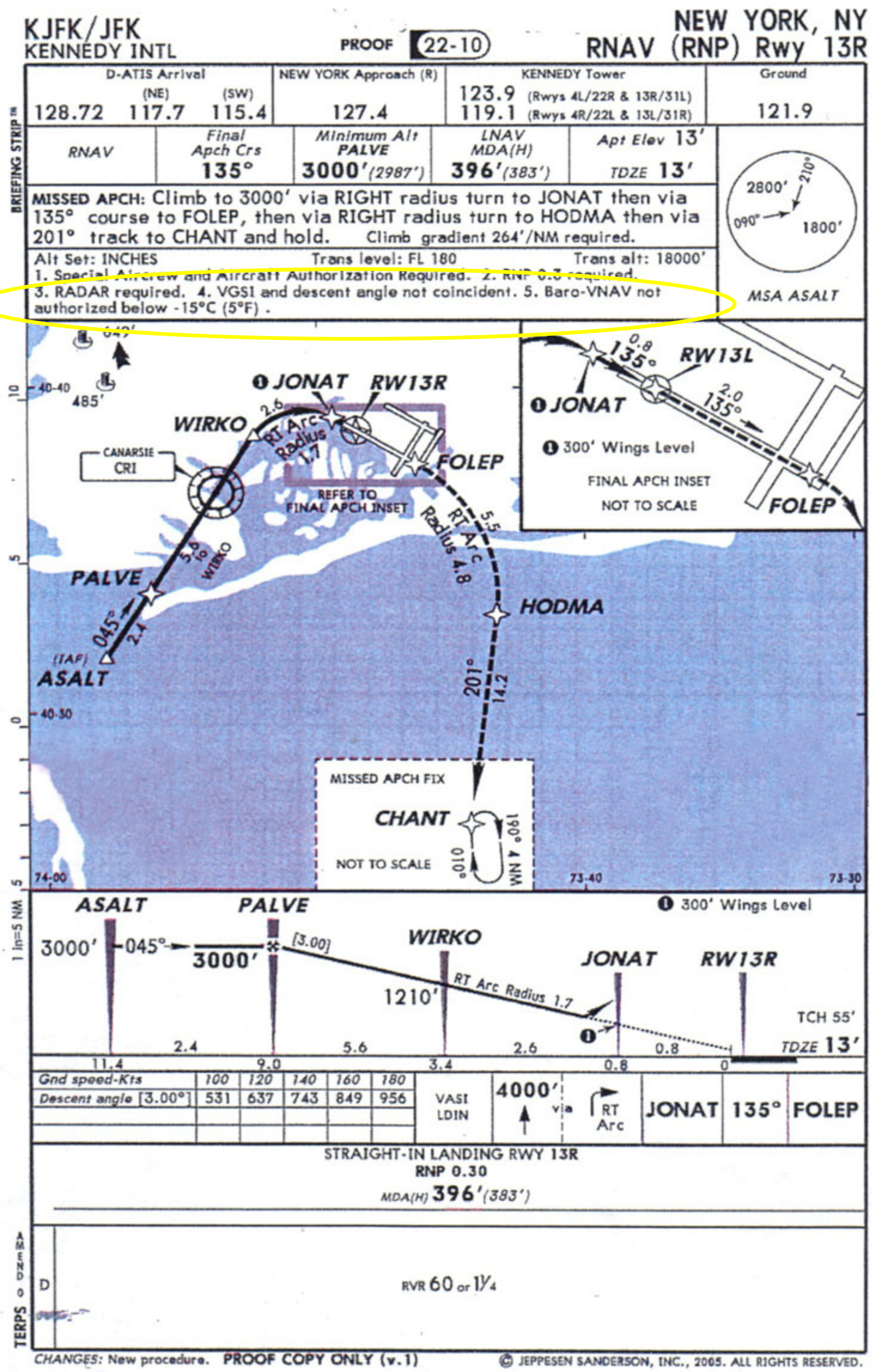


Figure 28

RNP RNAV Approach – Baro VNAV - Minimum OAT

Flying Technique Using FLS - IAN Modes

The Airbus FLS (FMS Landing System) and the Boeing IAN (Integrated Aircraft Navigation) guidance modes may be used for all straight-in non-ILS approaches coded in the FMS navigation data base.

The main goal of those modes is to allow to fly such approaches "ILS alike", which means that the procedures recommended to aircrews to fly non-ILS and ILS approaches are quasi-identical: Same sequence of actions, same controls and same displays.

However, since the FLS and the IAN are based upon approaches stored in the FMS navigation data base and since the performance of the guidance is linked to the FMS navigation accuracy, the same two precautions still apply:

- The check of the proper coding of the approach; and,
- The check of the FMS navigation accuracy.

The completion of the rest of the final approach is done with the same procedures as the one used for an ILS approach.

However, when reaching the DA(H) - or MDA(H) according to local regulations - the pilot must disengage the AP and hand-fly the visual segment of the final approach down to landing (i.e., no autoland capability).

Both above flying techniques allow to state that all non-ILS approaches should no more be considered as Non Precision Approaches – NPA's but as Precision-like Approaches, if flown accordingly.

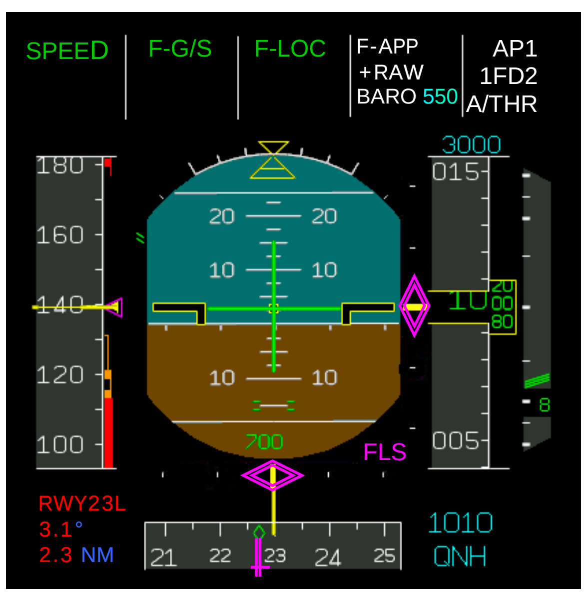


Figure 29

Airbus - EFIS PFD – FLS Modes

Kathmandu VOR DME Approach to Rwy 02

Today, the VOR DME approach into Kathmandu runway 02 is flown:

- By most operators, still using the step-down / dive-and-drive techniques, with all its drawbacks; or,
- By some operators, using the NAV / FPA modes on 3 successive constant descent-angle segments (i.e., -3.1°, -6.11° and –3.17°); this has significantly raised the safety level of this approach.

Tomorrow, a curved RNP RNAV approach, with a single constant descent-angle from the FAF to the runway will be available (refer to **Figure 30**), which will be flown in LNAV / VNAV (FINAL APP) modes down to DA, provided that the actual navigation performance of the FMS is within the required navigation performance (RNP 0.3).

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

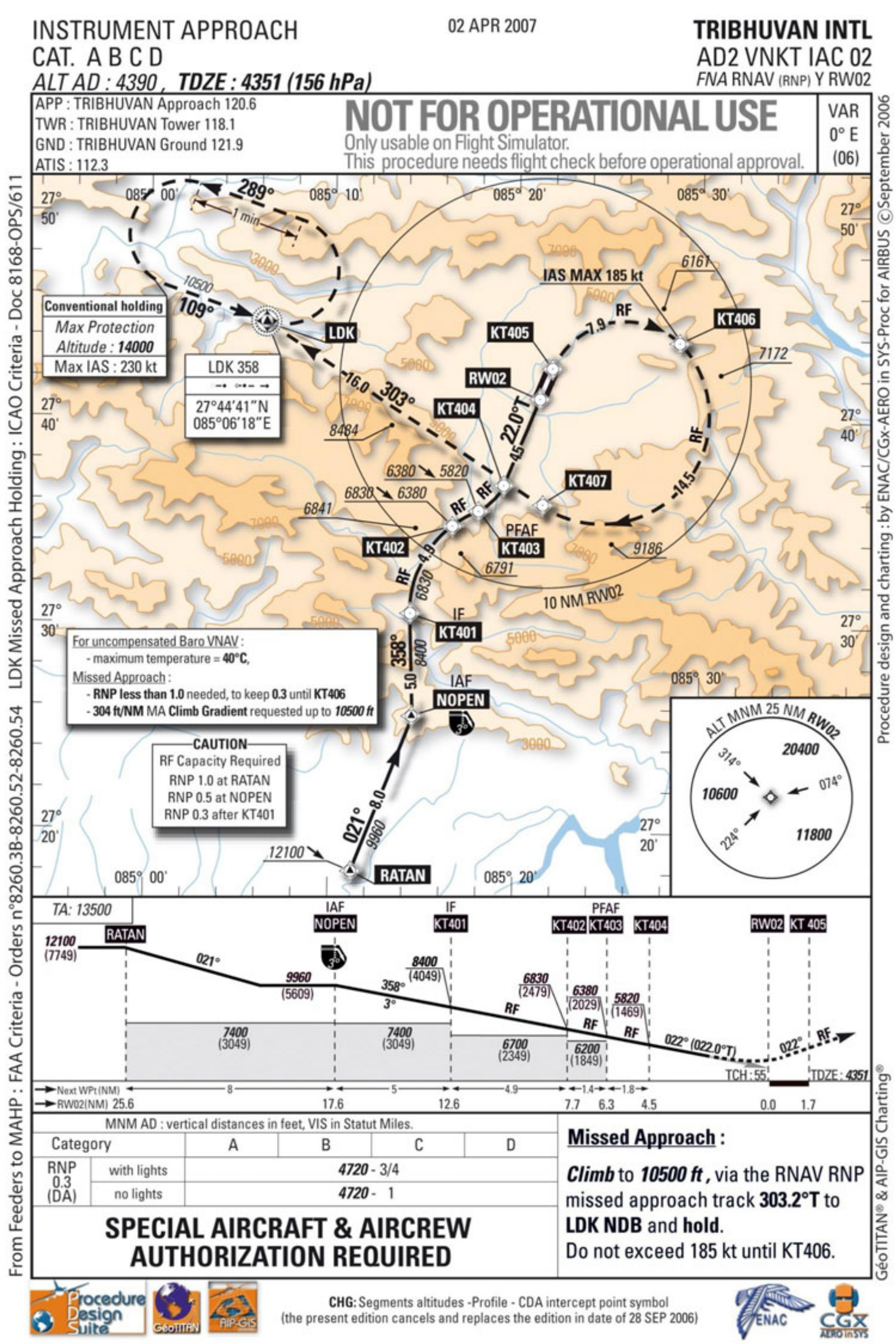


Figure 30

Kathmandu RNAV (RNP) SAAR Rwy 02 – Airbus Study

IV Summary of Key Points

The completion of a non-ILS approach is one of the most challenging and demanding phase of flight, which requires a proper planning and significant strictness from the crew in the conduct of the approach (task sharing, crew coordination, risk awareness and proper decision making).

The methods and procedures recommended to fly such approaches have significantly changed in the past decades:

- Those were step-down / dive-and-drive methods initially, which are still widely used, even on the latest-technology aircrafts, despite the flaws, the weaknesses and the drawbacks demonstrated by line experience; and,
- These are the today constant descent-angle / stabilized final approach techniques, which do significantly raise the safety level of this flight phase.

With the spread of GPS, and of latest technology glass-cockpits, all non-ILS approaches – from traditional NPA's to RNP RNAV approaches – may be flown using the latter technique.

The resulting procedures are very close to the procedures recommended to conduct ILS approaches; furthermore, the extremely high accuracy of the GPS associated to the high performance of the lateral and vertical modes of the AP / FD make the conduct of the non-ILS approaches very precise …

… This fully explains the shift in the operational vocabulary, from :

Non Precisions Approaches (NPA's), to …

ILS-like Approaches, and then to …

Precision-like Approaches.

V Additional Reading Materials / Website References

A series of four articles has been written to improve knowledge and awareness of precision-like approaches:

- Flight Safety foundation – AeroSafety World – September 2007 - Pursuing Precision

***Note**:*

*AeroSafety World can be found on the Flight Safety Foundation website: **http://www.flightsafety.org.***

VI Acknowledgements

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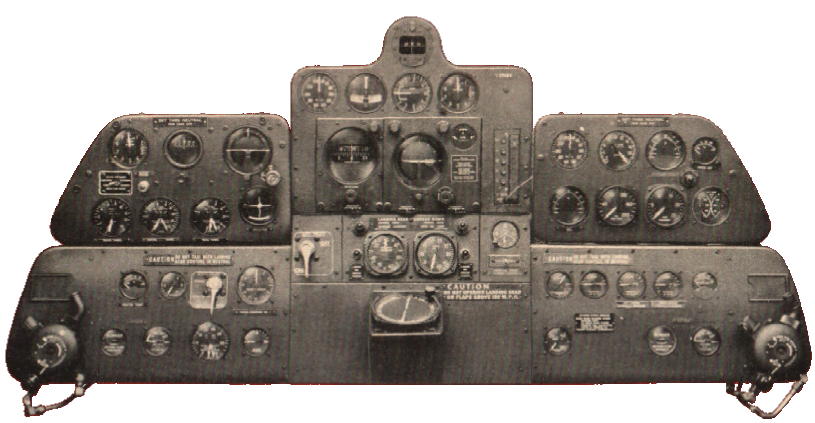

(Photo Credit – US Army Air Force – C46 Pilot Training Manual – Issue March 1945)

Curtis C46 Commando

Guidance and Display Functionalities – Mid-forties