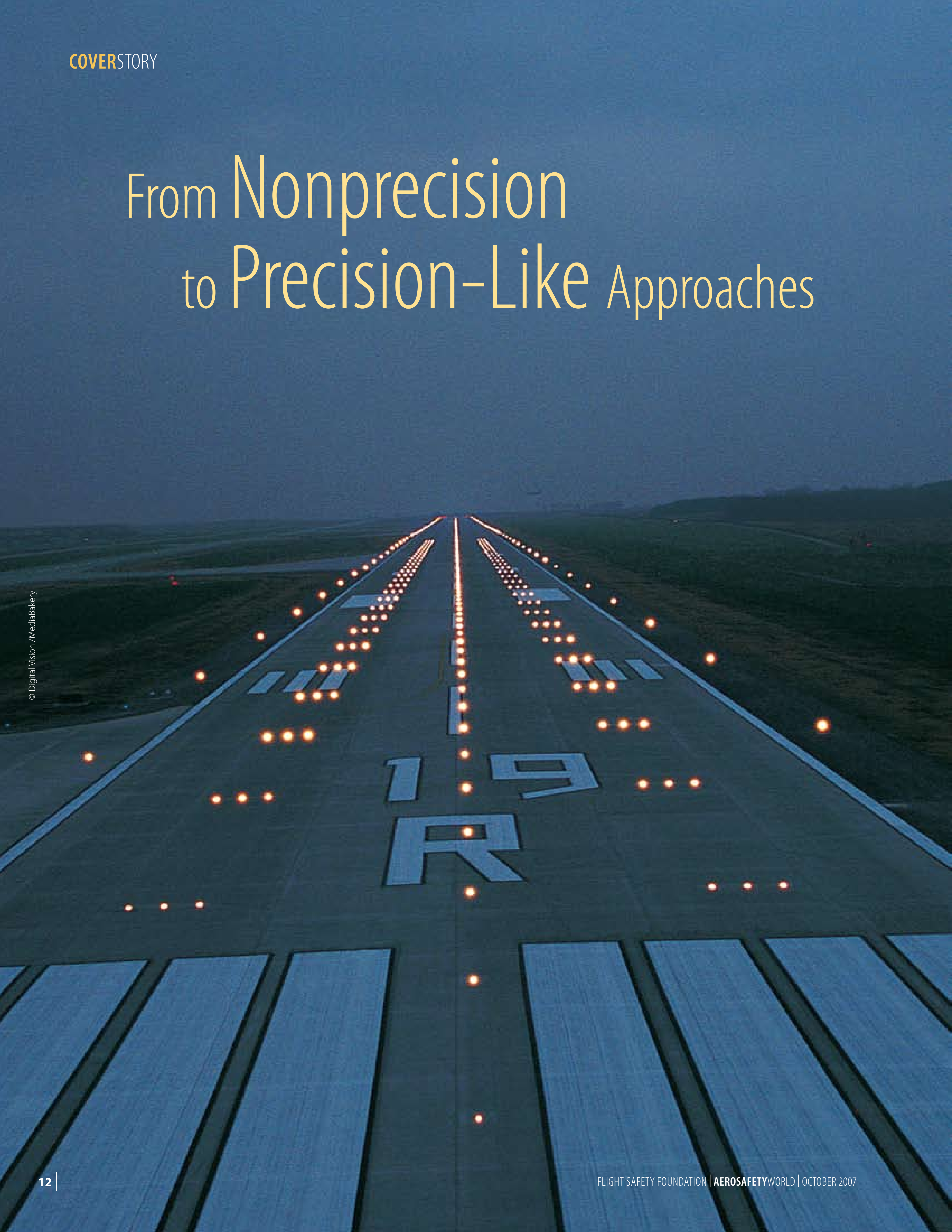
From Nonprecision to Precision-Like Approaches



Second in a series focusing on the development and safety benefits of precision-like approaches, a project of the FSF International Advisory Committee.

BY ETIENNE TARNOWSKI

Flying a nonprecision approach in traditional nonprecision ways is less safe than flying the same approach using the capabilities most transport aircraft today possess to fly a nonprecision approach in a precision-like manner. The FSF Approach and Landing Accident Reduction (ALAR) Task Force found that more than half of the accidents and serious incidents involving controlled flight into terrain (CFIT) occur during step-down nonprecision approaches. Other data showed that nonprecision approaches are five times more hazardous than precision approaches. The FSF International Advisory Committee believes there is insufficient attention being paid to the potential of using procedures that create precision-like approaches — how to fly them and how to design and approve them — despite the fact that most aircraft and flight crews are capable of using them.

The methods and operational procedures that have been recommended by aircraft manufacturers, airlines and operators for flight crews to fly non-ILS (instrument landing system) approaches have evolved over the past 35 years. They range from the traditional step-down approaches — also known as "dive-and-drive" or "stairway" approaches — of the 1970s, to the constant descent angle/stabilized approaches of the 1980s, to the precision-like approaches of the 1990s and onward.

The evolution has significantly improved safety; the latest procedures, when applicable, have suppressed the main causes of unstabilized approaches and, thus, have minimized the risks of CFIT during final approach and runway excursions and tail strikes during landing.

Any type of instrument approach procedure to a runway is a defined lateral and vertical trajectory to be flown in instrument meteorological conditions down to the published minimum altitude, where the required visual references must be acquired to safely continue the approach and landing.

A non-ILS approach has a lateral path supported by a radio navigation aid (navaid) and a vertical path defined in a more-or-less discontinuous way. With the advent of navigation sensors and airborne navigation equipment such as the global positioning system (GPS) receiver, inertial navigation system (INS) and flight management system (FMS), the area navigation (RNAV) point-to-point method of navigation, which is not dependent on ground-based navaids, has allowed more flexibility in the definition of final approach lateral and vertical paths.

Traditionally, most instrument final approaches have been flown "straight in" or, when clear of clouds, continued with a circle-to-land procedure. With the modern flexibility, segmented or curved final approaches have been defined.

Non-ILS Approaches

The non-ILS approaches typical of the 1970s are referenced to ground-based navaids used to form the final approach trajectory. The navaids include nondirectional beacons (NDBs), VHF omnidirectional radios (VORs) and localizers (LOCs) often paired with distance measuring equipment (DME).

They are called nonprecision approaches because their overall performance is dictated by the performance of the navaid — for example, plus/minus 5 degrees for an NDB, plus/minus 3 degrees for a VOR — and the location of the navaid — on the airport, close to the airport, on or off the extended centerline of the runway, and because there is no vertical path guidance.

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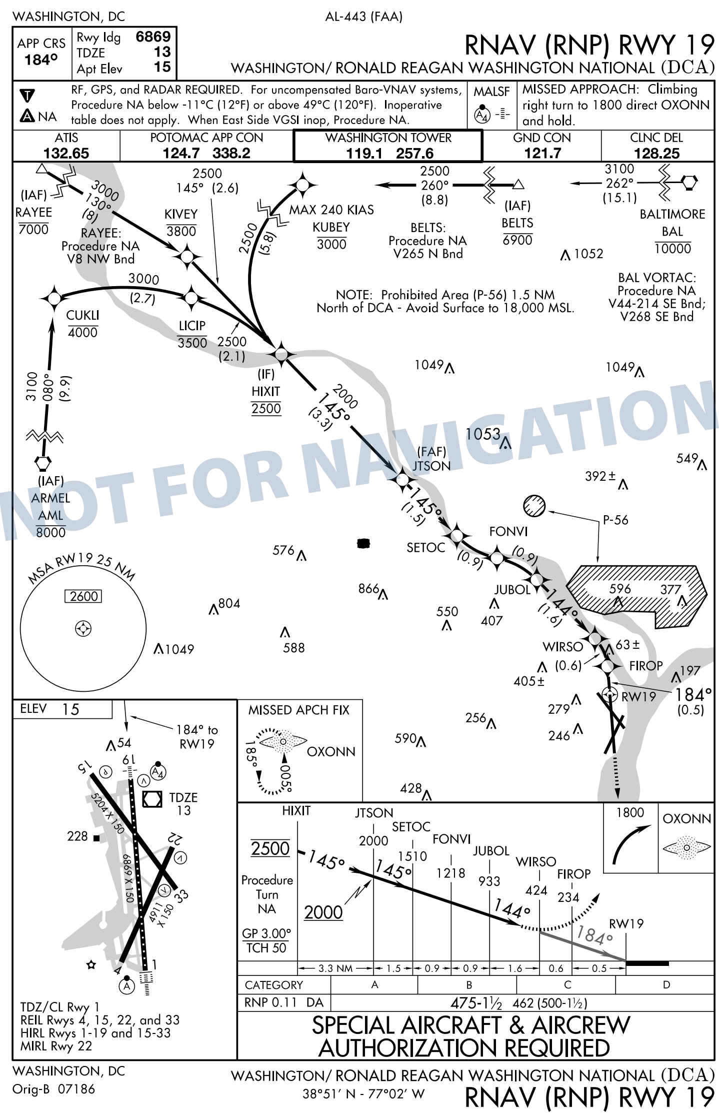
While the availability of DME helps the flight crew maintain awareness of the airplane's position along the lateral path, nonprecision approaches are characterized by poor definition of the vertical path of the final approach. Vertical path definition is partial and discontinuous, and often is provided only by an assigned altitude at the final approach fix (FAF) and by the distance from the FAF to the missed approach point (MAP). Thus, the crew's awareness of the airplane's vertical position versus the intended vertical path of the final approach is quite low.

The advent of RNAV approaches in the 1980s allowed adequately equipped airplanes to be flown point-to-point based on latitude and longitude coordinates that were assigned crossing altitudes. Consequently, RNAV approaches clearly define both a lateral and a vertical trajectory.

From the 1990s onward, required navigation performance (RNP) RNAV approaches have been defined basically as RNAV approaches with a *performance-based concept*, meaning that the airplane is capable of flying the RNAV approach trajectory meeting specific RNP accuracy levels — 0.15 nm, for example. Thus, the airplane's navigation system must monitor its actual navigation performance (ANP) — typically, total navigation error, including system error and flight technical error — and has to identify whether the RNP is actually being met during the approach.

The performance-based concept ensures that the airplane remains *contained* within the specified volume of airspace, without requiring an outside agent to monitor its navigation accuracy and integrity. This concept gives great flexibility to approach designers; indeed, the notion of containment allows designers to consider approach trajectories that can satisfy various complicating and potentially conflicting constraints such as terrain, noise, environment and prohibited areas. The concept ensures a comfortable, flyable, constant descent angle vertical path, with approach minimums dictated by RNP. Figure 1 is an example of an RNP RNAV approach procedure.

Required Navigation Performance Approach



Source: U.S. Federal Aviation Administration

Figure 1

Position-Fixing

The methods and procedures recommended to fly non-ILS approaches obviously depend upon the ability of the on-board equipment to ensure the functionalities of navigation, guidance and display.

In the 1970s, the navigation functionalities essentially were based on equipment that received radio navigation signals from ground-based stations. Some airplanes had an INS that could be updated by ground-based signals. Other systems, such as long-range navigation (LORAN) and Omega, were used for long-range navigation where accuracy requirements were relatively low.

Two major steps forward in the 1980s were the widespread use of INS and the adoption of the FMS. Many transport airplanes were equipped with a least one INS, which computes the airplane's position autonomously, and at least one FMS, which also computes the airplane's position. The FMS provides lateral and vertical flight planning functions by stringing together all the legs of a flight, including the approach. The FMS can assign crossing altitudes at various waypoints of the approach, as well as a descent angle for specific legs, such as the final approach.

From the 1990s onward, the major advance in navigation technology has been achieved through the use of GPS, which is accurate, available worldwide, able to reliably specify its performance and capable of monitoring its integrity. GPS is used as a primary navigation source by the FMS. The resulting FMS-computed position is extremely accurate. The navigation databases used by the FMS have been upgraded, and, whenever required, the descent angles assigned to specific legs also are included in the database for a better determination of approach profiles.

Tracking a Trajectory

Guidance functionalities used by crews to fly approaches in the 1970s included the conventional attitude director indicator (ADI), vertical speed indicator (VSI) and altimeter. Early autopilots and flight directors with basic modes aided in the crew's ability to fly instrument approaches.

Enhancements to FMS performance allow the ability to fly any type of non-ILS approach with great precision.

In the 1980s, guidance functionalities were greatly improved by the "glass cockpit," in which the electronic flight instrument system (EFIS) featured new guidance cues such as the flight path vector (FPV). The FPV assists the crew in stabilizing segments of trajectory, particularly during final approach.

The FMS developed further and allowed additional autopilot and flight director modes better suited for tracking a trajectory. These guidance enhancements included lateral navigation (LNAV) and vertical navigation (VNAV).

From the 1990s onward, guidance functionalities have been improved by increased use of the head-up display (HUD) and by continued enhancements of the FMS. The basic flying reference in a HUD is the FPV, which allows the crew to control the airplane's trajectory in relation to external references, such as the runway. The enhancements to FMS performance allow the ability to fly any type of non-ILS approach with great precision and, thus, to meet RNP criteria.

Additionally, specific FMS "approach" modes have been developed to provide flight crews with common methods and procedures when flying any straight-in approach, ILS or non-ILS. These modes are part of the integrated approach navigation (IAN) system in Boeing airplanes and the FMS landing system (FLS) in Airbus airplanes, in which the FMS computes a virtual "beam" to the runway, based on the FMS flight plan, as illustrated by Figure 2. These new modes allow the crew to monitor deviations from the beam and make corrections similar to an ILS approach. Figure 3 is an example of an IAN-adapted display.

Increased Awareness

Displays present the crew with the information required to adequately monitor a non-ILS approach.

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

This information was displayed by the radio magnetic indicator (RMI) during NDB and VOR approaches, and by the electronic horizontal situation indicator (EHSI) for VOR and LOC approaches. The addition of DME improved the crew's awareness of the airplane's position along the bearing indicated by the EHSI or RMI.

In this period, the crew's awareness of the airplane's vertical position versus the intended vertical path generally was very poor. The VSI, altimeter, clock and DME were used to estimate the airplane's position. The advent of EFIS displays in the 1980s brought the primary flight display (PFD) and the navigation display (ND), which is directly linked to the FMS.

Linking the FMS to the ND greatly improved the crew's lateral orientation by showing the direct relationship of the current path to the intended path. The PFD displays the vertical deviation from the intended final approach path, as selected in the FMS.

Since the 1990s, display functionalities have been further enhanced to the point that most non-ILS approaches can now be flown as precision-like approaches, provided that the adapted pieces of information are displayed for crew situational awareness. Furthermore, the development of the RNP performance-based concept has led to specific monitoring requirements.

The evolution of display functionalities may be summarized as follows: profile views of the approach displayed at the bottom of the ND for enhanced vertical situational awareness; and, on the PFD and ND, displays adapted to RNP, which has lateral and vertical deviation scales and annunciations tailored to IAN or FLS.

Factors Affecting Procedures

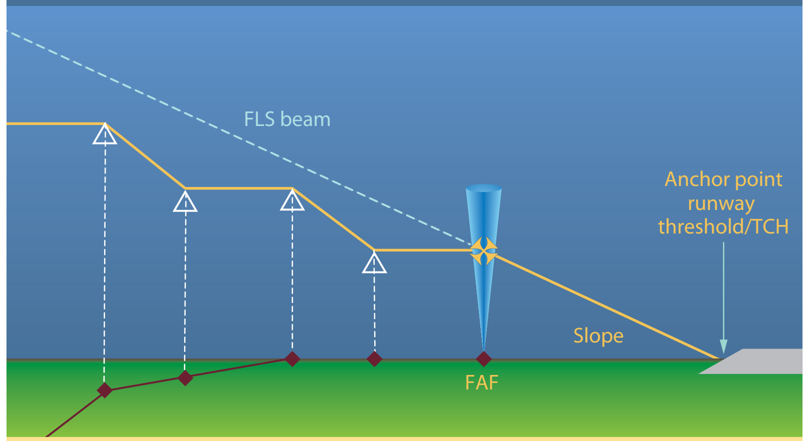
As noted earlier, the methods and procedures recommended to fly non-ILS approaches depend on the nature of the non-ILS approach and the on-board equipment. The procedures are affected by additional factors associated with the approach.

One factor is the position of the FAF, which is either defined as a geographical point on a straight-in approach or estimated by the crew — for example, at the end of the procedure turn of a teardrop approach.

Another factor is the position of the MAP, which may be located at the runway threshold or before or beyond the runway threshold.

The nature of the minimum altitude also affects the procedure. No altitude loss below the minimum descent altitude (MDA) is allowed during the approach and go-around. This applies to either the level-off at the MDA or, in the case of a constant descent angle, a go-around initiated before reaching the MDA, to keep from going below that altitude. This is not required when the minimum is a decision altitude (DA). If the required visual runway environment

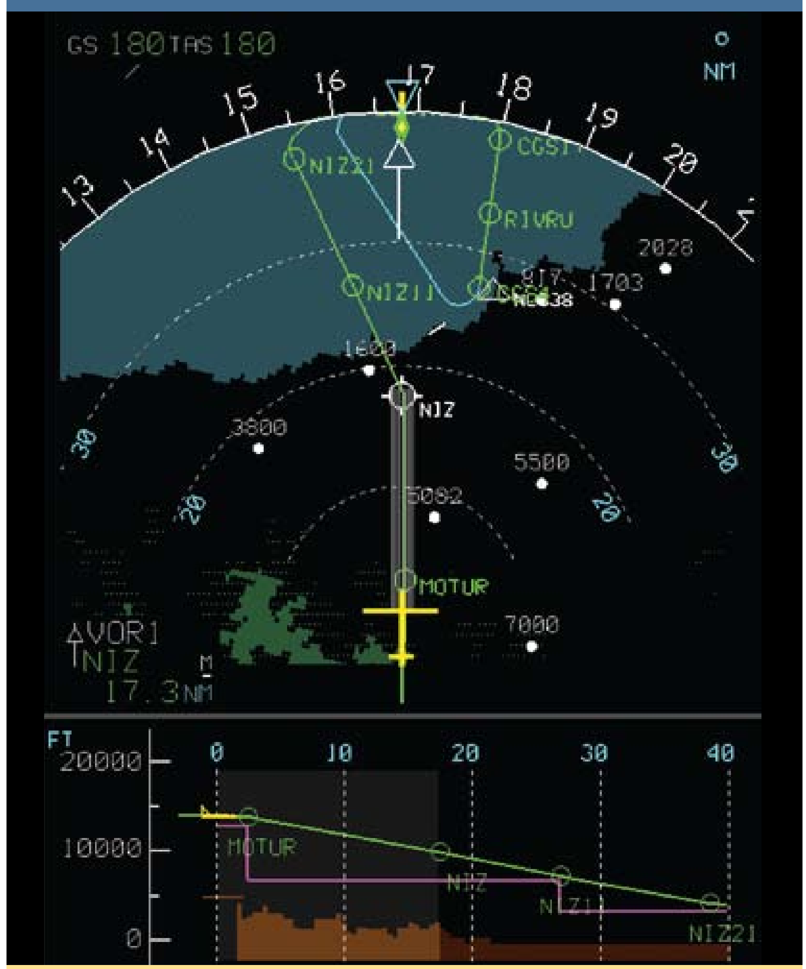
FMS Landing System Beam



Source: Etienne Tarnowski

Figure 2

Profile View on Display



Source: Etienne Tarnowski

Figure 3

references are not acquired when reaching the DA, a go-around must be initiated.

Considering all these factors, let us review the evolution of non-ILS approach procedures in the three periods discussed.

The non-ILS approach procedures in the 1970s were the traditional nonprecision approaches using NDBs, VORs, LOCs and, possibly, DME as reference navaids. On-board equipment was conventional in terms of navigation, guidance and display functionalities. Two types of methods and procedures were recommended; they differed only in the control of the vertical flight path, whereas the control of the lateral flight path was similar. Also common then, as today, was the recommended use of the autopilot to reduce workload and provide more precise tracking.

Lateral flight path control was accomplished by tuning the reference navaid, setting the RMI and EHSI for the approach to be flown, and setting the final approach course as a target trajectory. Most crews used the heading mode to track NDB approaches and the LOC or VOR mode for those approaches. Once visual references were acquired, at MDA at the latest, the approach was completed visually and manually.

Control of the vertical path was accomplished by two different methods and procedures. Both methods assumed that the airplane was being flown in the landing configuration and at the final approach speed from the FAF down to the landing or initiation of a go-around. One method was the traditional step-down/dive-and-drive/stairway method, as illustrated by Figure 4. This involved using the autopilot pitch or vertical speed mode, leveling off at the step-down altitudes and at the MDA, and transitioning to a visual final approach and landing. This method involved flight path changes at low altitudes.

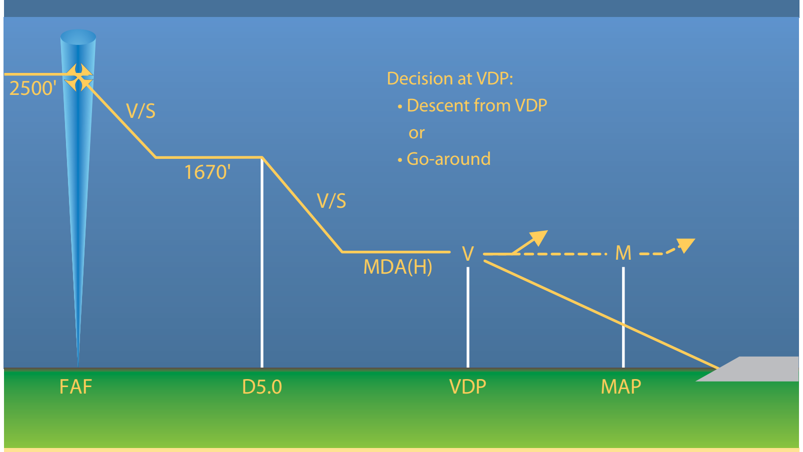
For non-FMS/non-glass-cockpit airplanes, the traditional dive-and-drive method was recommended down to MDA. The recommended procedure was to select a vertical speed of 1,000 fpm at the FAF, level off at the next step-down altitude and monitor DME or make altitude checks as available — and to repeat these steps to MDA. If the required visual references were not in sight at an altitude equal to MDA plus 10 percent of the descent rate — for example, MDA plus 100 ft for a typical 1,000 fpm descent rate — the vertical speed was reduced to level off at the MDA.

This method could result in reaching minimums past the published or calculated visual descent point (VDP). The VDP is the last point from which a stabilized visual descent 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 as a period of time to fly from the FAF.

This method was recommended for all nonprecision approaches by some operators that often flew NDB approaches without DME and without a published vertical descent angle or rate of descent, so as to have a common procedure for all non-ILS approaches they flew.

However, this traditional step-down approach method has drawbacks. The airplane is never stabilized during the final approach. The pitch attitude needs to be changed even at low altitudes; thus, thrust and pitch have to be continually adjusted. Additionally, the airplane reaches the MDA in level flight either before

Dive and Drive



Source: Etienne Tarnowski

Figure 4

or after the VDP. Consequently, pitch attitude affects the acquisition of visual references and visual perspective of the runway. Furthermore, if past the VDP, the crew is tempted to continue visually at a high descent rate. This technique leads to unstabilized approaches, which have been shown to result in off-runway touchdowns, runway excursions/overruns and tail strikes.

Constant Descent Angle

The second method that evolved during the 1970s was the constant descent angle approach, which enables the crew to continue a stabilized approach to a landing once visual references have been acquired (Figure 5).

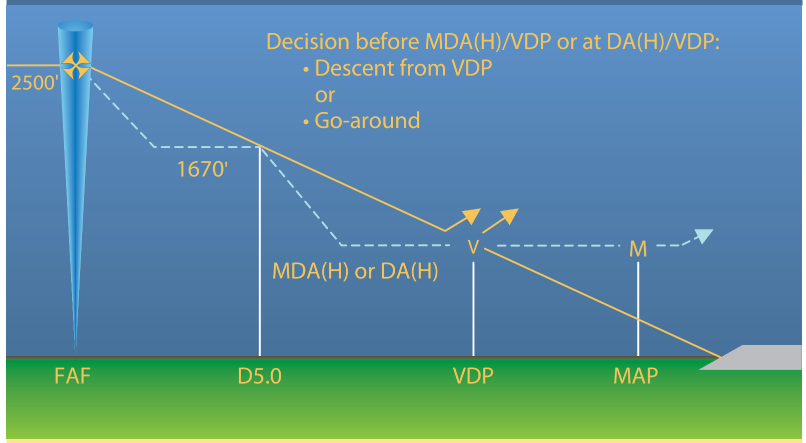
The principle of this method is for the crew to compute a vertical speed adequate to fly from the FAF to the VDP on a constant descent angle. This is a function of average groundspeed during approach. Some approach charts provide a table of altitude versus groundspeed to enable the crew to fly a constant descent angle. If such a table is not provided, the crew must estimate the time between the FAF and the VDP to establish the required vertical speed.

Consequently, during the intermediate approach segment, the crew estimates the average groundspeed, determines the constant vertical speed to be flown and estimates the VDP if one is not published. Upon reaching the FAF, the vertical speed mode is selected and the appropriate descent rate is established. The descent must be monitored by distance/altitude checks or the elapsed time if DME is not available. The monitoring must be increased as the airplane nears the VDP.

No descent below MDA is allowed if the required visual references are not acquired; a go-around must be initiated immediately. No level-off at the MDA should be considered, because with most published MAP positions, delaying the go-around decision would not allow the crew to complete a stabilized visual segment.

The advantage of the constant descent angle approach method is that the airplane is stable during the final approach, with pitch attitude, speed, thrust and pitch trim remaining constant. When reaching the VDP, the visual perspective of the runway is familiar, which allows a proper assessment of whether the approach can be continued visually and safely. The transition to visual flight is continuous, and monitoring of the vertical path is simple.

Constant Descent Angle



Source: Etienne Tarnowski

Figure 5

The Concept of Trajectory

In the 1980s, RNAV approaches were added to the mix of non-ILS approaches. EFIS and glass cockpits, FMS and improved flight director modes favored the concept of trajectory with improved flight planning. Consequently, lateral and vertical guidance, referenced from the FMS position, could be provided along a trajectory retrieved from the FMS navigation database.

The improved guidance capability allowed the tracking of this approach trajectory with little vertical deviation. While some operators still recommended the traditional step-down method, they also took advantage of the map display for improved lateral situational awareness. Many operators adopted the procedures recommended by the manufacturers, which took advantage of FMS features to support constant descent angle approaches.

Two precautions applied to full use of the FMS. The first was that the crew had to ensure that the FMS position was accurate and that its accuracy was within the tolerances of the

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approach — typically, within 0.3 nm. If the accuracy was within tolerances, the LNAV/VNAV modes and displays could be used. If not, other lateral and vertical modes had to be used, and a display of raw data had to be monitored for situational awareness. An inaccurately computed position directly affects the performance of FMS guidance and renders the map display misleading.

The second precaution was that the crew had to check the quality of the FMS navigation database. The final approach could not be modified by the crew. Therefore, the crew was required to check the FMS waypoints for final approach against those published on the approach chart. If these two precautions were satisfied, the FMS and its associated guidance modes and display functionalities could be used.

Segment by Segment

The constant descent angle approach method can be summarized by looking at the initial, intermediate and final approach segments. During initial approach, the crew checks FMS navigation accuracy and selects the reference navaid raw data. Then, the crew checks the final approach as inserted in the FMS against the published procedure, paying particular attention to the DA.

During the intermediate approach, the crew reduces airspeed and configures the airplane in the landing configuration. The final approach radial is intercepted via the FMS navigation mode or an intercept to the FMS final course. The crew must monitor the interception with raw data and ensure that the correct mode is selected to track the radial on final approach.

Prior to reaching the FAF on final approach, the crew must ensure that the airplane is established in landing configuration and at the final approach airspeed. At the FAF, the crew must ensure that the airplane descends on the proper path using the appropriate FMS mode, then monitor the descent both vertically and horizontally, and set the missed approach altitude in case a go-around is required. If the required visual references are acquired before or upon reaching the DA, the crew disengages the autopilot and hand-flies the rest of the approach visually, maintaining the same descent path to land. If the required visual references are not acquired, a go-around must be conducted.

The methods and procedures recommended during the 1980s emphasized stabilized approaches and constant descent angle approaches. The advantages of a stabilized approach are better horizontal and vertical situational awareness, speed awareness and energy awareness, with thrust being maintained close to the level required to fly the final approach descent angle at the final approach airspeed.

The constant descent angle approach ensures a profile that offers greater obstacle clearance along the final approach course, a technique and procedure similar to those for an ILS approach, significantly reduced crew workload, a pitch attitude that facilitates acquisition of visual references to land, and greater fuel efficiency and less noise impact on nearby communities.

GPS Precision

The coming of GPS in the 1990s, with its extremely high navigation performance and integrity-monitoring capability, has greatly affected the way non-ILS approaches are flown and has allowed full implementation of the RNP performance-based concept.

In addition, the enhancement of display and guidance functionalities has further reinforced the stabilized/constant descent angle final approach method. Thus, all non-ILS approaches now can be flown like ILS approaches and, due to GPS, may be considered as precision-like approaches.

Two methods are recommended today to fly precision-like approaches. Which method is appropriate depends on the geometry of the approach and the aircraft equipment.

The first method involves the use of final approach — LNAV/VNAV — autopilot guidance modes and is applicable to all approaches coded in the FMS navigation database. The procedure is similar to the previously discussed constant descent angle/stabilized approach procedure. The same precautions must be taken regarding checking FMS navigation accuracy; however, because GPS monitors its performance and integrity, the crew receives alerts when the navigation performance is not satisfactory, GPS capability is lost or the RNP level is not satisfied. The same precautions also must be taken regarding checking for correct coding of the final approach waypoints in the FMS database.

The same flying technique applies, but with these considerations. If an RNP RNAV approach is being flown, the deviations provided on the PFD are scaled to RNP. Because VNAV is guiding the airplane on the flight path angle provided by the FMS, if the outside air temperature (OAT) is significantly lower or higher than standard, the barometric VNAV guidance will guide the airplane on a shallower or steeper flight path than expected. This explains why approach charts specify minimum and maximum OATs to operate with VNAV. These approaches are flown down to the DA or MDA, depending on local regulations.

The second method involves the use of the Airbus FLS or Boeing IAN mode. These guidance modes apply to all straight-in non-ILS approaches coded in the FMS navigation database. The main goal of the modes is to fly such approaches as "ILS alike," which means that the procedures recommended to flight crews for both ILS and non-ILS approaches are nearly identical: same sequence of actions, same controls and same displays.

Because these approaches are flown using the FMS navigation database, the same two precautions apply as in full use of the FMS described earlier: check the coding of the approach waypoints and check FMS position accuracy. The approach is then flown using procedures identical to flying an ILS approach. However, when reaching DA (or MDA), the crew has to disengage the autopilot and hand-fly the final segment down to landing.

Further enhancements of navigation accuracy eventually will allow autopilot-coupled nonprecision approaches to very low visibility limits and autolands. Such approaches already have been demonstrated.

Conclusion

The completion of a non-ILS approach is one of the most challenging and demanding phases of flight. Proper planning and significant strictness by the flight crew are required in the conduct of the approach, including task sharing, crew coordination, risk awareness and proper decision making.

The methods and procedures recommended to fly such approaches have significantly changed over the past decades. Unfortunately, the initial step-down/dive-and-drive methods are still widely used, even by crews of the latest-technology airplanes, despite the flaws, weaknesses and drawbacks that these outdated methods have exhibited in line operations.

Today, stabilized, constant descent angle final approaches significantly raise the safety level of this flight phase. With the spread of GPS and the latest technology glass-cockpits, all non-ILS approaches can be flown using the latest methods. The resulting procedures are very similar to the procedures recommended to conduct ILS approaches.

Furthermore, the extremely high accuracy of GPS, associated with the high performance of the lateral and vertical modes of the autopilot and flight director systems, makes the conduct of non-ILS approaches very precise.

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

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