THE SAFETY GAINED BY EQUIPMENT AND PROCEDURES USED TO PERFORM CONSTANT ANGLE APPROACHES

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Abstract

The Flight Safety Foundation (FSF) has documented the risks of non-precision approaches. Findings have led to a call for expediting the worldwide implementation of constant angle or precision-like approaches and for training pilots to use these procedures. Industry has met this call by developing equipment and procedures that essentially, if implemented worldwide, would eliminate many accidents and fatalities.

The Safety Gained by Equipment and Procedures Used to Perform Constant Angle Approaches

The Flight Safety Foundation (FSF) documented in the *Approach and Landing Accident Reduction (ALAR) Tool Kit* and other publications the risks of non-precision approaches. The FSF ALAR Task Force found, for example, that more than half of the accidents and serious incidents involving controlled flight into terrain (CFIT) occur during step-down non-precision approaches. Other data showed that non-precision approaches are five times more hazardous than precision approaches. These findings led to a call for expediting the worldwide implementation of constant angle or precision-like approaches and for training pilots to use these procedures. Industry has met this call by developing equipment and procedures that essentially, if implemented worldwide, would eliminate many accidents and fatalities. This paper will outline the on aircraft equipment improvements over the last 20 years, the associated procedural changes that were implemented, the risks and mitigations associated with these approaches, and finally an outline of the benefits of flying these approaches. .

Terms and Concepts of Vertical Guidance

“All-weather operations” is a term typically used to describe the use of non-precision and precision instrument procedures to conduct low-visibility takeoff and landing operations. The need for all-weather operations was recognized in the earliest days of aviation when the need arose to expand operational capabilities and improve safety. The need to fly at any time drove the requirements for marking and lighting airways, designating landmarks and lighting and marking airports. It also led to the replacement of road maps with aviation-specific charting, beginning with the detailed notes taken by Elrey Jeppesen during mail runs, and the establishment of rules of the air, including instrument flight rules (IFR) and visual flight rules (VFR), and air traffic separation services, primarily for flying in bad weather.

The evolutionary steps included improvements of aircraft equipment — gyroscopic flight instruments and radios, for example — and external aids, including light beacons at first and later radio beacons such as the four-course visual-aural radio range (VAR), non-directional beacon (NDB), marker beacons and eventually the VHF Omni-directional radio (VOR). Simply finding the destination airport in bad weather was hard enough in the early years of aviation. Aligning with the runway and descending precisely during the final stages of a flight typically were tasks accomplished after visual contact was made with the field. The early goals of instrument approach procedures were to define a safe lateral path and specify safe minimum altitudes for the approach and missed approach. This led to the largely two-dimensional nature of non-precision instrument approach procedures based on the four-course range, NDB, VOR and later the localizer.

By the end of World War II, instrument flying had evolved to the point of enabling aircraft flight capability in most instrument meteorological conditions (IMC), albeit with significant safety risk. A comprehensive system of radio navigation aids (navaids), including radio ranges and NDBs, was deployed; charts depicting airways and instrument approach procedures were published; and the early foundations were laid for an airway system comprising VORs. Early instrument landing systems (ILSs), which provide precise alignment with the runway centerline as well as high-quality vertical guidance to a relatively low height, began to appear. ILS and ground-controlled approaches (GCAs) were the first real attempts to define a precise lateral path to a runway centerline and a corresponding precise vertical path to fly until the pilot could see the runway to visually complete the approach with a flare and touchdown. These approaches later became known as precision approaches, or three-dimensional approaches, because they provided specific vertical guidance as well as lateral guidance. Meanwhile, NDB, VOR and tactical air navigation (TACAN) systems and procedures continued to evolve. Their use expanded globally, in parallel with evolving ILS approaches and ground-controlled approaches using precision approach radar (PAR), systems that were significantly more expensive to install at airports. Some approaches also required additional expensive airborne equipment. Hence, ILS and PAR installations were limited to deployment and use at large, busy airports where operators typically required all-weather-operations capability. ILS was predominant for air carriers that needed and could afford to install the required aircraft equipment.

Since localizer signals could be received by aircraft — typically, general aviation aircraft — that did not have glide slope receivers, both localizer and back course localizer approach procedures were established to provide more users at least a partial benefit from ILS systems, albeit only two-dimensional guidance. The minimum height to which an aircraft could descend on a non-precision approach originally was called the minimum descent altitude (MDA); for a precision approach, the label decision altitude (DA) was applied. Weather minimums for landing and takeoff were specified with both a visibility component and a ceiling, or cloud base, component. For a variety of reasons, both economic and technical, the ILS eventually prevailed over PAR and ground-controlled approaches. This occurred initially for civil operations, because ILS technology provided more operational flexibility at lower cost and supported lower landing minimums

Meanwhile, the use of NDB, VOR and localizer approaches increased globally during the 1960s through 1980s, primarily for economic reasons, including the lower cost of ground and aircraft equipment, compared with ILS. Unfortunately, the safety record of flying non-precision approaches did not match the improved safety record of precision approaches flown with ILS. In the 1970s and 1980s, aircraft navigation systems significantly evolved to include multi-sensor flight management systems, electronic displays and area navigation (RNAV) equipment. RNAV capability included either two-dimensional lateral navigation (LNAV) alone or three-dimensional navigation employing both LNAV and vertical navigation (VNAV).

By the end of the 1980s, it became apparent that the stability and accuracy of a well-defined three-dimensional FMS-based path continuing to the runway had both safety and operational benefits, including simpler crew procedures and reduced noise emissions. FMSs enabled the use of RNAV-direct routings and LNAV/VNAV navigation on published standard instrument departures (SIDs) and standard terminal arrival routes (STARs). Where ILS approaches were not available, RNAV techniques could be applied to most other instrument approach procedures. Air carriers applied three-dimensional RNAV using BARO VNAV on a large scale. For FMS-equipped aircraft, which became the air carrier norm, nearly all non-precision instrument approach procedures could be flown using the LNAV and VNAV modes. Inclusion of global positioning system (GPS) inputs to multi-sensor FMSs became common for air carrier aircraft, with a significant increase in the accuracy available to fly any three-dimensional instrument approach trajectory. Because of the widely recognized safety advantage of flying vertically stabilized VNAV paths to the runway, operators have been using FMS BARO VNAV while conducting NDB, VOR and localizer approaches. As a result of these initiatives, more operators now are using VNAV for any suitable non-precision approach procedure, even if a vertical path is not published as part of the procedure. Similarly, for aircraft that do not have an FMS or VNAV capability, the constant-descent approach (CDA) technique was developed to obtain at least some of the benefit of a stabilized approach and to avoid procedures that have been most vulnerable to human failures, particularly step-down — “dive-and-drive” — non-precision approach procedures. The CDA technique is based on the use of distance-altitude checks or a pre-planned vertical speed to mimic a VNAV path.

Required navigation performance (RNP) is a refinement of RNAV, applied in a much more systematic and uniform way. Unlike other types of approach procedures, which have angular navigation design criteria resulting in reduced accuracy as distance from the navaid or waypoint increases, RNP has linear navigation design criteria. The standard RNP approach performance value is 0.3 nm, meaning that the aircraft is capable of being flown within 0.3 nm of the course or path centerline, regardless of distance from the waypoint. RNP has shown major operational and safety benefits and has become the foundation for the future of global navigation, according to ICAO’s Future Air Navigation System (FANS) plan and the U.S. Federal Aviation Administration’s Performance-Based Navigation Roadmap.

Ground-based augmentation likely will be needed indefinitely to support GNSS-based landing system (GLS) approaches and RNP approaches, to provide comprehensive navigation services, including air carrier Category III landing and low-visibility takeoff operations. RNP has demonstrated significant safety, economic and operational benefits. All Airbus and Boeing aircraft currently in production are RNP-capable, and increasing numbers of other aircraft types are being RNP-equipped. RNP is an ICAO standard, an element of the FAA’s Performance-Based Navigation Roadmap and is being implemented in many other states — including Australia, Canada, China and New Zealand — as well as states in Europe. Now entering commercial service, GNSS-based landing systems (GLSs) provide “better-than-ILS” capability and extend flight operations for suitably equipped aircraft to the lowest Category III landing minimums at any airport with a ground-based augmentation system, as well as nearby airports that are covered by the primary airport’s GBAS.

Methods and Operational Procedures

The methods and operational procedures which have been defined by aircraft manufacturers, airlines and operators for pilots to fly non-ILS approaches have evolved in time over the past 35 years. The evolution of these procedures has been dictated by the following factors: The way non-precision approaches (NPA’s) or the precision-like approaches is defined, the navigation sensors used, and the instruments used to fly and monitor the approach.

The methods and procedures provided to fly instrument approaches in IMC have varied in time since they depend on two main factors: the nature of the approach and the onboard equipment. In the seventies these approaches are referenced to a ground radio navaid used to form the final approach trajectory or pattern. These navaids, since the last 30 years, were typically NDB's, VOR's/LLZ's (LLZ refers to LOC-only and LOC back course), coupled or not to a DME. These approaches are named non-precision because the overall performance of these approaches is dictated by the performance of the navaid (NDB +/- 5 degrees, VOR +/- 3 degrees, etc.) and the location of the navaid (on the field, close to the field, on or off the extended centerline of the runway). Additionally, the availability of DME as part of the reference navaid helped the pilot to locate the airplane position along the lateral path. Lastly, the non-precision nature of the approach is also caused by the lack of a defined vertical path of the final approach. Crew awareness of the airplane vertical position versus the intended vertical path of the final approach is quite low.

In the eighties, with the advent of RNAV approaches, the airplanes were flown point to point based on latitude and longitude coordinates which were assigned a crossing altitude. Consequently, RNAV approaches clearly define both a lateral and a vertical trajectory. In order to fly such RNAV approaches the airplane has to be equipped with adequate equipment.

Starting in the nineties and onward, RNP RNAV approaches were basically defined as RNAV approaches with a performance-based concept. This concept means that the airplane is able to fly the RNAV approach trajectory and to match a Required Navigation Performance (RNP) e.g. RNP 0.15 nm. Thus, the airplane navigation system has to monitor its Actual Navigation Performance (ANP), typically the total navigation error (system and flight technical error), and has to identify whether the RNP is actually met or not during the approach. This concept gives 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, etc. All this and ensure a comfortable, flyable, constant descent-angle vertical path, with approach minima's dictated by RNP.

The methods and procedures recommended to fly non-ILS approaches obviously depend upon the cockpit systems and the onboard equipment to ensure the functionalities of navigation, guidance, and displays. Navigation functionalities are those which provide the pilot with the best estimation of the airplane position and its deviation versus an intended flight path (vertically or laterally). In the seventies the navigation functionalities were essentially based on radio navigation receivers. They received signals from ground based stations. Some airplanes had INS which could be updated by certain ground based signals. Other systems such as LORAN, Omega, were used for long range navigation where accuracy requirements were relatively low. In the eighties two major steps forward were the widespread use of INS and the adoption of the Flight Management Systems (FMS). Most airplanes got equipped with a least one IRS unit, which processed the airplane position autonomously and permanently with a decent performance level. Additionally, most airplanes got equipped with at least one FMS which processed permanently the aircraft position and ensured flight navigation functions. The FMS achieves lateral and vertical flight planning functions by stringing together all the legs of a flight including 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. From the nineties onward the major impact was from the use of GPS. This is because of its accuracy, its ability to properly estimate its performance, its worldwide and permanent availability, and its capability to monitor its integrity. GPS is therefore used as a primary navigation sensor by the FMS which outputs also the navigation performance. The resulting FMS computed position is extremely accurate, which explains the shift in the vocabulary form non-precision approach to precision-like approach, when flying an instrument final approach using the GPS as basic navigation sensor.

Guidance functionalities are those which are used by the pilot to fly an approach. In the seventies the pilot used the conventional attitude indicator (ADI), VSI (Vertical Speed Indicator) and altimeter to control a descent or climb gradient. Early autopilots and flight directors with basic modes aided in the ability to fly these approaches. In the eighties we saw the advent of two major items greatly improving guidance functionalities. These were glass cockpits where EFIS (Electronic Flight Instrument System) replaced ADI's featuring new flying cues such as the Flight Path Vector (FPV). The other guidance item was FMS. It allowed additional autopilot and Flight director modes that were better suited for tracking a trajectory. These included LNAV for the lateral guidance and VNAV for the vertical guidance. From the nineties onward, the guidance functionalities have been affected by the spread of the head-up display (HUD) as well as by enhancements to FMS modes. The basic flying reference in a HUD is the FPV which allows the pilot to control the airplane trajectory against the outside world references, such as the runway. Additionally, specific "approach" modes have been designed to provide flight crew with identical methods and procedures when flying an approach as an ILS would give them. These modes are called IAN (integrated approach navigation) for Boeing's and FLS (FMS landing system) for Airbus aircraft. The principle of these modes is that the FMS computes a virtual beam upstream of the runway based on the FMS flight plan. These new modes allow crews to monitor deviations from the beam and make corrections similar to an ILS approach.

Display functionalities are those which provide the crew with the information required to adequately monitor the achievement of the non-ILS approach. The essential information provided in the seventies was the position of the airplane relative to the intended lateral trajectory of the approach, e.g., the airplane current radial to the reference navaid, versus the approach intended radial. The addition of DME improved crew awareness of the aircraft position. Overall, in this period, the crew awareness regarding the aircraft vertical position versus the intended vertical path was very poor. The VSI, altimeter, clock, and DME were all used to make this estimate. In the eighties, a major step forward was the advent of EFIS displays. These include the Primary Flight Display (PFD), and the Navigation Display (ND), the ND being directly linked to the FMS. The FMS linked to the ND has greatly improved the lateral orientation of pilots by showing the direct relationship to the intended path. In the nineties and onward the display functionalities have been enhanced. Consequently, most non-ILS approaches can now be flown as precision-like approaches, provided adapted pieces of information are displayed for crew situational awareness. Furthermore, the development of the required navigation performance (RNP) concept has led to specific requirements in terms of monitoring. The evolution of display functionalities may be summarized as follows: vertical situational displays added at the bottom of the ND for enhanced vertical situational awareness, on the PFD and ND displays adapted to RNP which has lateral and vertical deviation scales and annunciation tailored to IAN or FLS.

Considering all those factors, let us review the evolution of the non-ILS approach procedures in the three steps in time we previously considered in this article. In the seventies, lateral flight path control can be summarized by tuning the reference navaid, set the RMI and EHSI for the approach to be flown, set the final approach course as a target trajectory. Most pilots used the Heading mode to track NDB approaches and the LOC or VOR mode for those approaches. The control of the vertical path of the airplane used two different methods and procedures. The first vertical method was the traditional step down/dive and drive/stairway method. This involves using autopilot pitch or vertical-speed modes, leveling off at step-down altitudes and at MDA, 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 an ILS approach. This traditional step-down approach technique had drawbacks. The airplane was never stabilized during the final approach. This technique led to unstablized approaches which have been shown to lead to off-runway touchdowns, runway excursions/overruns and tail strikes.

The second method used during that time was the constant angle approach method. The principle of this method is for the crew to compute the adequate vertical speed to fly from the FAF to the VDP on a constant angle path. This is a function of average ground speed during approach. On certain approaches, constant-angle descent tables are provided. If these tables are not provided the pilot estimates the time between the FAF and the VDP to establish the required vertical speed. Consequently, during the intermediate approach a pilot should assesses the average ground speed, determines the constant vertical speed to be flown and estimates the VDP if not published. Upon reaching the FAF the vertical speed mode is selected and the appropriate vertical descent established. The descent must be monitored by DME altitude checks or the elapsed time if DME is not available with increased monitoring nearing the VDP. The advantages of this technique is that the airplane is flying stable during the final approach with pitch attitude, speed, thrust and pitch trim remain constant. When reaching the VDP the perspective view of the runway is similar, which allows a proper assessment if the approach can be continued visually and safely. The transition to the visual segment is continuous and monitoring of the vertical path is simple.

In the eighties the non-ILS approaches were the traditional NPA's as well as RNAV approaches. The improved guidance capability allowed the tracking of this approach trajectory with little vertical deviation. While some operators did still recommend the traditional step-down method they did take advantage of the map display which provided improved lateral situational awareness. Two precautions were essential to fly those approaches using fully the FMS. The first precaution was that the pilot had to ensure that the FMS position was accurate and that its accuracy was within the tolerances of the approach (typically within .3 nm). If the accuracy was within tolerances then the LNAV/VNAV modes and displays could be used. If the FMS navigation accuracy was not within tolerances then other lateral and vertical modes needed to be used and a raw data display used on at least one side for situational awareness. An inaccurate FMS position directly affects the performance of this guidance and renders the map display misleading. The second precaution was that the pilot needed to check the quality of the FMS navigation data base to ensure the final approach was correctly inserted. The final approach could not be modified by the crew. The crew was required to check the FMS waypoints for final approach with the published procedures. If these two precautions were satisfied, then the FMS, and its associated guidance modes and display functionalities could be used. The constant-angle descent approach ensured a profile which offered greater obstacle clearance along the final approach course, offers a technique and procedure similar to an ILS technique to include the go-around and missed approach, significantly reduced pilot workload, provides a pitch attitude the facilitates acquisition of visual references to land and finally is more fuel efficient and reduces noise levels for nearby communities.

From the nineties onward the coming of GPS, with its extremely high navigation performance and integrity-monitoring capability, has really affected the way non-ILS approaches are being flown. Two methods are recommended today to fly these approaches and it depends on the geometry of the approach and the aircraft equipment.

The first method is using Final Approach (LNAV/VNAV) autopilot guidance modes. This technique is applicable to all approaches coded in the FMS navigation data base. The procedure is similar to the one provided in the previous discussion on constant-angle stabilized approaches. The second method is using the FLS – IAN modes. The Airbus FLS and Boeing IAN guidance modes do apply to all straight-in non-ILS approaches coded in the FMS navigational data base. The main goal of those modes is to fly such approaches "ILS alike" which means the procedures recommended to aircrews to fly both ILS and non-ILS approaches are nearly identical: same sequence of actions, same controls and same displays. Both of the methods allow us to state that all non-ILS approaches should no longer be considered as non precision approaches but as precision-like approaches, if flown accordingly. This explains the shift in the operational vocabulary from Non Precision approaches (NPA's) to ILS-like and then to Precision-like Approaches.

Risks and Mitigations

Dive and Drive is the antithesis of the stabilized approach recommended by the Flight Safety Foundation (FSF). Constant Angle Non-Precision Approaches are conducted the same way normal visual and precision approaches are conducted The essential element for conducting a safe approach is to assure the aircraft passes "At or above" all step down altitudes from the final approach fix until approaching the MDA. If the required visual elements to continue to landing have not been located prior to reaching MDA, a missed approach climb must be executed. These approaches required less time at minimum obstacle clearance heights and reduce the likelihood of altitude busts due to high sink rates. Finally, the same visual reference points as used during precision approaches are used to determine aircraft position and attitude relative to the runway. While flying level at the MDA, using the dive and drive techniques, many pilots feel they are too high as they approach the Visual Descent Point (VDP) because the runway appears much lower in the windscreen than it would on a normal descent path. It usually results in excess nose down pitch and high sink rates from MDA to the runway.

Non-precision approach is a misnomer. Non-precision approaches are the most difficult of all approaches and require a much higher degree of concentration and team work than when flying an ILS approach. There are about a dozen different ways/techniques to fly non-precision approaches verses precision ILS approaches. There are many traps for the unprepared when required to conduct a non-precision approach.

1. Premature Descent: A review of historical non-precision approach mishaps shows the greatest risk is from a premature descent. There are many possible reasons for a premature descent:

2. DME Location Errors: There can be a false assumption of the DME location or the VOR or LOC in relationship to the airfield or runway end.

3. There can be an incorrect altimeter setting reported by ATC Controllers.
4. There can be minimum obstacle height violations by the crew failing to add corrections to minimum crossing altitudes when significant errors in actual Vs indicated altitudes have been caused from unusually low temperatures.

5. The ATC Controller may have prematurely cleared the aircraft for descent, or given a late turn on or kept the aircraft too high, resulting in rushing the approach. Controllers have also cleared the incorrect aircraft to descend.

6. A late change to the landing runway can lead to distractions.

7. A failure to work as a team greatly increases the risks during a non-precision approach.

8. Failure to observe SOPs for approach and landing has resulted in inappropriate configurations, airspeed too high, excessive descent rates at the 1000 feet, 500 feet gates, and violation of minimum altitudes.

Some tools that help determine safe altitudes or altitudes on approach and a stable approach are:

a) The Radio Altimeter (RA) installed on virtually all modern transport aircraft can be invaluable to cross check the pressure altimeter.

b) Radio Altimeter aural, tones, voice callouts or advisories can be invaluable on approach to help provide some awareness of the terrain below along the approach and an advisory when approaching the Minimum Altitude for the particular approach.

c) Ground Proximity Warning Systems (GPWS) can provide alerts for an unsafe terrain clearance if not in landing flaps and gear down configuration.

d) The E-GPWS (TAWS) is installed on a number of large commercial jet aircraft.

e**)** A Vertical Situation Display (VSD) that depicts terrain and the projected flight path ahead of the aircraft is another valuable tool to crosscheck the appropriate flight path and altitude along the approach.

f) The Weather Radar, in ground mapping mode and appropriately ranged, is another tool to cross check the aircraft's horizontal aircraft position, especially when significant terrain exists along the approach or an approach is being made across water to an airport located on higher ground.

g) If your aircraft is fitted with a Head up Display (HUD), this a great tool to monitor the approach and help stabilize the aircraft's flight path with relationship to the runway on approach and landing.

h) If your aircraft is fitted with Flight Management Tools to conduct a Constant Angle Approach, learn to use them, understand their limitations and the importance of initiating the approach at the correct distance from the runway or fix and the importance of altimetry.

The Benefits of Constant Angle Approaches

One of the key items in any person's or entity's business case is the protection from absolute disaster – insurance to allow survival. Safety specialist often point out that "if you think safety is expensive then you should see the cost of an accident". Since the non-precision approach accident rate is 4 to 8 times higher than a precision approach it makes sense for an airline to move to as much of a precision approach like operation as possible. Even if the airline adopts these methods and does not experience an accident, there are other gains and improvements that are fallout of conducting constant angle approaches.

One of the "clear" improvement areas for constant angle approaches is in the area of our environment. The amazing thing about this is that it can be basically accomplished by a dedicated transition from traditional approaches, even precision approaches, with the airplanes an airline owns today. Directly related to the emissions improvement is the reduction of fuel used with constant angle approaches. With the advent of modern navigation capability, mainly RNP based, ever increasing numbers of carriers are finding success and benefits in conducting these approaches routinely. Another direct effect to the environment of conducting constant angle approaches is the reduced noise levels. Further improvements can be made with the consistent use of constant angle arrivals and approaches. Idle or near idle descents greatly reduce engine noise levels. Because level segments are not planned for on arrivals and approaches the overall descent gradient of the approaches can be steeper. This can be a welcomed improvement for those who live under a typical level segment at a busy airport.

The business case for training is certainly a powerful one. In today's environment crews must be trained and maintain proficiency in many types of approaches. The use of the most modern methods of RNP arrivals and descents gives the capability of greatly reducing the number of types of approaches crews must be trained for. Essentially, in today's environment, all approach training should be to an ILS or RNP based constant angle approach to maximize the savings discussed earlier and results in reduced training requirements. Another benefit that can be gained is lower minimums on approaches. With RNP values set, trained, equipped, and flown low enough, the results can be outstanding. Airlines that have been using these techniques have reported numerous diversion "saves" where RNP constant angle approaches have allowed operations to continue when before an expensive diversion would have been required. Of course, satisfied customers were on those flights also! The same precise horizontal and vertical navigation that allows the airplane to consistently fly constant angle RNP approaches allows airlines to have further benefits in the area of increased payloads or range. The business case for constant angle RNP based approaches doesn't just stop with the airlines. The regulators, airports, and air traffic control all achieve benefits also.

In the future we will see all approaches conducted as a single uninterrupted idle or near idle descent from top of descent to short final. RNP augmented approaches are capable of conducting consistent precision constant angle approaches down to category 3 type weather minima today. With this capability we can safely have these approaches to nearly every airport runway end worldwide without the massive infrastructure and navigation aid investment we have today.

For many airlines and pilots the future is now. They are making the changes and investment needed to conduct these constant angle approaches and operations. They are seeing the benefits in the many areas we have discussed. Most importantly they are doing it safely, using proven methods and modern tools.

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