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Contents

1	Background	4
2	Approach	4
3	Boundaries	4
3.1	GPS related hazards	4
3.2	Airborne equipment related hazards	4
3.3	NPA procedure design related hazards	5
3.4	Air Traffic Control	5
4	Impact of the use of GPS for NPA operations	5
4.1	General	5
4.2	GPS as a positioning system	5
4.3	Use of a database for GPS approaches	7
4.4	GPS integration in the aircraft	7
4.5	Impact on crew	7
4.6	Impact on ATC	8
4.7	Procedure design	8
5	Relative safety assessment	9
5.1	Safety benefits of using GPS	9
5.2	Safety hazards of using GPS	9
5.3	Hazard Classification	10
6	Conclusions	10
7	Recommendations	11
8	Reference documents	12

(15 pages in total)

Operational Safety Implications of GPS based Non-Precision Approach Operations

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Manfred Dieroff graduated in Aeronautical Engineering in 1986 at the Technical University of Braunschweig, Germany, and

has been working until 1995 as research engineer in the field of flight control systems and flight test. Between 1995 and 1996 he has been working for an avionics manufacturer for certification of hybrid GPS/IRS systems. In 1996 he joined the German Air Navigation Services where he is now responsible for basic navigation issues and has responsibility for the safety investigation regarding GPS based approach procedures in Germany. In parallel to the engineering education, he holds an air transport pilot licence.

Abstract

This paper summarises the results of a qualitative safety investigation into non-precision approach operations supported by GPS. The objective of the study is to verify the assumptions made with respect to the safety of GPS-NPA operations in comparison with the typical German NPA operations based on NDB/DME.

The study was carried out under assignment of the Deutsche Flugsicherung. In the study a number of benefits, as well as hazards, of the introduction of GPS for NPA operations were identified. Without nullifying the potential safety benefits, the qualitative assessment shows that especially crew training is a critical issue when evaluating the GPS NPA operation (compared to the current NDB/DME procedure, with which pilots are well experienced). The current population of pilots, especially from General

Aviation, is in general not yet trained for the use of GPS equipment for IFR operations. If no additional migration measures are introduced, it is expected that initially the introduction of GPS NPA operations may lead to a less safe operation compared to the current conventional NPA. At the same time it is recognised that over time pilots will get more experienced in the use of GPS.

Therefore, with the application of safety management to ensure proper crew training, the team is confident that GPS NPA operations promise a safer operation than the current NPA operation.

1 Background

In order to permit civil aviation to use satellite navigation for en-route flights and non-precision approaches as soon as possible, the DFS has developed a strategy for the implementation of satellite navigation in three subsequent stages. The first stage introduces the use of satellite navigation as an additional navigation aid and is completed. The second stage allows the use of satellite based systems completely independent from the conventional, terrestrial navigation systems and the third stage allows the reduction of the terrestrial navigation aids.

For the approval of the second implementation stage (the use of satellite based systems independently of conventional terrestrial navigation aids) the ongoing evaluation program is complemented with an analysis of the assumptions with respect to the effects on safety on which the German strategy is based.

2 Approach

The qualitative assessment of the *relative* safety of GPS-based NPAs is performed by comparing the differences of the GPS-based NPA with the NPA based on conventional radio navigation aids. For that purpose, first a clear description of the conventional NPAs is compiled, then a list of hazards consisting of differences between GPS and conventional NPAs is compiled. This list of differences is used for the actual *relative* safety criticality analysis.

The NLR approach to perform a qualitative safety assessment of any new concept, system, procedure or measure in air traffic is based on the AMJ 25.1309 of the Joint Aviation Requirements [RD- 3, page 3-X-27]. The methodology used in the study recognises five steps:

- Step 1: Identification of boundaries
- Step 2: Identification of hazards
- Step 3: Preliminary hazard analysis
- Step 4: Hazard classification
- Step 5: Decision making

3 Boundaries

3.1 GPS related hazards

As different studies have already focused on the assessment of the GPS performance, the draft ICAO GNSS SARPs [RD- 1] are taken as a baseline. The specific risks associated to the GPS satellite system (such as satellite failures) are therefore not considered in this safety assessment.

3.2 Airborne equipment related hazards

It is assumed that the airborne equipment is certified according to the JAA and LBA certification requirements [RD- 3, RD- 5

RD- 6]. Therefore any specific hazards related to the design of the airborne equipment is not considered.

3.3 NPA procedure design related hazards

It is also assumed that the non-precision approach procedure is published according to the relevant ICAO PANS-OPS criteria. The additional constraints applied by DFS when publishing NPA procedures in Germany are taken into account in the analysis.

3.4 Air Traffic Control

The availability of radar control to monitor the stand-alone NPA operation is not a mandatory requirement. For those airports where ATC is not available (class F airspace), specific restrictions are applied:

- Only one IFR operation at a time;
- Large passenger transport aircraft operations are not allowed;
- VFR traffic has to establish radio contact circa 5 min prior to entering the respective airspace or circumnavigate the airspace, if VMC minima for class F airspace are not existing; and
- IFR routes are depicted on the VFR approach plate.

4 Impact of the use of GPS for NPA operations

4.1 General

The nominal changes to the NPA operation with the introduction of GPS relative to the conventional NDM/DME operation include changes to:

Flight path: With the new operation the flight path is independent from the

geographical location of beacons. Therefore standardisation in the procedure design can be pursued.

Beacons: The availability of beacons as a reference during the operation is not taken into account as the stand-alone GPS NPA operation is considered contrary to the current overlay procedures.

GPS performance: With the introduction of GPS the position information in the aircraft is based on GPS instead of radio navigation beacons (NDB/DME). Its impact has been considered.

Display: In principal the available displays are used. However the GPS display may contain different information (position of aircraft with respect to ground track or VOR radial) instead of direction of the beacon. Usually the information is displayed on the Horizontal Situation Indicator (HSI) in the primary field of view of the pilot.

Selection of waypoints: With the introduction of GPS the air crew must be able to handle waypoints to generate route information such as "distance to next waypoint".

Database: The waypoints are selected by the air crew. The co-ordinates of the waypoints are based on information from a database.

ATS information: in the pre-flight planning ATC provides information related to the availability of GPS integrity (Predictive RAIM).

4.2 GPS as a positioning system

Compared to NDB, GPS offers different system characteristics. The following relative issues where introduction of GPS

lateral navigation can influence the safety of the operation have been identified:

1. Interpretation of presented lateral information;
2. Susceptibility to weather conditions;
3. Accuracy;
4. Integrity.

Information presentation

The NDB offers the pilot a relative bearing to the beacon. To follow or intercept a desired ground track the pilot has to work out a required heading. Especially in unknown and changing cross-wind conditions, translating the bearing information to a required heading is at most an inaccurate process.

On the other hand even the low-end GPS receivers display cross-track error and actual track. This information makes it easier for the pilot to spot cross-track errors and manoeuvre the aircraft towards the desired ground track.

Susceptibility to weather conditions

NDB has been reported to show highly unreliable indications, with sustained erroneous inaccuracies of over 30 degrees, during thunderstorms. Also milder rainstorms can influence the NDB signal whereas the GPS is shown to be merely insensitive to these conditions.

Accuracy

With respect to the accuracy characteristics, GPS does not share some specific NDB error characteristics:

1. GPS position accuracy is independent from the position relative to a beacon.
2. GPS does not suffer from a 'cone-of-silence', which normally has to be overflowed at a critical phase in the final approach.

3. Fluctuations on the GPS position are negligible compared to the fluctuations on the NDB signal.
4. GPS accuracy is independent of the surrounding geographical site.

A major improvement in terms of safety can be derived from these characteristics. Furthermore, with the improved accuracy, combined with the additional information to the pilot, it is expected that the rate of go-arounds from a GPS approach will be lower than the rate resulting from conventional NPAs.

Integrity

The integrity of the GPS navigation solution for the NPA operation depends on the Receiver Autonomous Integrity Monitoring (RAIM) capability of the airborne receiver. The airborne certification requirement is such that RAIM will provide an integrity warning in the cockpit if the GPS accuracy can not be sustained within the required alarm limit. Accurate GPS position information can only be computed if sufficient satellite coverage is present. Therefore, the operation using GPS has the drawback that it is dependent on satellite availability at the time and location of the (planned) operation. The RAIM algorithm requires a minimum of 5 and preferably 6 satellites, which reduces the overall availability of GPS/RAIM to around 97%. To facilitate pre-flight planning, DFS has implemented a RAIM predicting tool for the GPS NPA operations.

More sophisticated integration techniques using other positioning sensors such as the integrated navigation System (INS) can be used to augment GPS integrity as well.

4.3 Use of a database for GPS approaches

In principle, the GPS provides nothing but positioning information. Therefore in most GPS systems a database of waypoints is used to compute guidance information to the (auto)pilot. Any mistake (or inaccuracy) in the database information is directly translated in a navigation error of the aircraft.

Both RTCA and ICAO have defined standards on the required accuracy and integrity of the database information [RTCA Do200A, RTCA Do201A, ICAO Annex 14 & 15]. Besides the performance requirements also the quality assurance process is defined of how the data must be handled. Navigation databases that are used in GPS receivers or FMSs are produced by commercial vendors or airlines and are based on information in the AIP.

Large errors in coding can be detected by flight checking the procedure at least once prior to publishing the procedure for public operation, a policy already adapted by DFS. However the crew is ultimately responsible for the navigation of the aircraft, and an in-flight check of the navigation information (i.e. database) remains the responsibility of the pilot. Tools for this cross-check should be given to the crew (SOPs, published data on the approach sheet comparable to the data format applied in the GPS or FMS database), e.g. a check on Missed Approach Waypoint (MAWP, normally the runway threshold) coordinates and the distance and track between Final Approach Waypoint (FAWP) and MAWP could be prescribed in SOPs.

4.4 GPS integration in the aircraft

TSO compliant implementation of airborne GPS receivers in airborne navigation systems can be achieved at different levels

of integration with existing aircraft avionics. Differences can occur with respect to:

- GPS stand-alone vs. GPS as position input to an FMS (GPS+IRS+RNAV) position;
- GPS guidance only vs. GPS guidance coupled to an autopilot;
- GPS lateral position/guidance only vs. GPS-aided FMS with VNAV capabilities;

It is noted that, although a TSO approval has been issued, some interfaces to GPS receivers are not always perfect with respect to ease of operation. The chance of 'fingertrouble' is sometimes evident.

The success of the introduction of GPS depends highly on the prudent use of certified sensors/databases and the actual integration with the flight management system (FMS) and the autopilot.

Standard Operating Procedures (SOPs) can aid the pilot in applying the correct actions at opportune moments in the approach.

4.5 Impact on crew

Due to the complexity of the NDB/DME operation, the conventional non-precision approach includes many hazards related to the pilot workload. It is clearly evident that the pilot workload is a critical item, influencing a potential lack of situational awareness with the pilot of the aircraft's position relative to the procedure. During the evaluation of the GPS trial in Germany since the 8th of October 1998, all pilot reports state a decrease in the pilot workload and an improved situational awareness. This being a positive conclusion with respect to the safety of the operation, care must be taken that the crew is not 'overconfident' on the presented picture.

Quality assurances within major airlines must mitigate the special risks involved with these type of operations. Required SOPs, charting procedures, approach minima, and required aircrew training will and must be part of the process of introduction of GPS as a NPA. For smaller operations it is quite common that training requirements are fulfilled on the line or at a commercial training institute, charts are bought from Jeppesen without customization, SOPs are less developed, and operational scrutiny by quality assurance programs is less well developed. To monitor these operations, pilots must now demonstrate their ability to perform GPS-approaches to the authorities on their annual proficiency check. It is not postulated that this means these operations are less safe, but the size of the operation does not justify the requirements large operators have with respect to crew training and operational quality assurance. It is believed that especially the latter group will benefit from safety measures already built into the introduction of GPS approaches.

Operational pitfalls

From the flight trials, a number of specific pitfalls associated with GPS procedures relating to crew issues was mentioned by the airlines involved in the trial. They will be introduced here for further analysis in the Qualitative Assessment in the following chapters.

- § Timely arming of the approach required; to obtain properly scaled guidance and cross-track error indications, the pilot is required to ARM and ACTIVATE an approach prior to the Initial Approach Waypoint (IAWP) and FAWP respectively.
- § Short line-ups: positioning the aircraft on the final approach track within the FAWP may introduce unwanted

responses with just about every GPS-implementation.

- § Last-minute changes to the navigation plan: contrary to conventional NPAs, last-minute changes to the navigation plan (initiated by either the pilot or ATC) are not easily accommodated, resulting in increased head-down time and increased workload.

4.6 Impact on ATC

In theory the new operation should not affect the air traffic control operation. However, Air Traffic Controllers should be aware of some shortcomings:

- § The way the approach is defined using non-changeable waypoints the clearance "Direct-To" a waypoint that is not defined in the active flight plan of the GPS procedure can not be easily accommodated in the FMS: it is possible that the approach is cancelled and guidance reverts to terminal sensitivity.
- § Furthermore, as has been mentioned in the previous paragraph, ATC should refrain from providing radar vectors inside the FAWP.

4.7 Procedure design

The way the procedure is designed is in line with the PANS-OPS criteria. The use of waypoints is expected to contribute heavily to operational safety: the design of the procedure is no longer limited by the geographical position of the radiobeacons. This flexibility should be used by future procedure-designers by applying a GPS approach template where possible. This will lead to a familiar picture to the pilot everywhere a GPS approach is executed.

From the operators involved in the flight trials, some issues related to procedure design that have been mentioned:

- A possible confusion between GPS distance-to MAWP and DME readings could lead to the aircraft being positioned on the wrong glidepath.
- when an intermediate stepdown-waypoint is published in the procedure, this could lead to distance-to-stepdown-waypoint being misread for distance-to-missed-approach-waypoint and vice versa.

5 Relative safety assessment

This study is limited to safety issues related to the introduction of GPS NPAs, economical issues were intentionally not addressed. It was found that a number of issues promise to enhance the level of safety, while others constitute potential hazards to safety, particularly in the implementation phase.

5.1 Safety benefits of using GPS

The technical system characteristics of GPS (superior accuracy compared to NDB, pilot interface flexibility and the possibilities for the procedure-designer) have brought up a number of issues that can increase the level of safety of the operation. These issues, as identified in Table 5, are:

- presentation of relevant navigation information
- less susceptibility of navigation system performance for adverse weather conditions
- increased, and more consistent, position accuracy
- go-around rate and lateral path following in the missed approach phase
- Support of RNAV/LNAV and VNAV
- decreased pilot workload
- improved situational awareness

- possibility for a consistent design of the NPA procedure

5.2 Safety hazards of using GPS

Issues that constitute hazards were subject to a hazard analysis and classification process. This is described in more detail in [RD-1]. Combining a probability of occurrence with an independently assessed severity class leads to a qualification of the hazard category.

Safety critical hazards are identified to have at least one element of the analysis in the "unacceptable" region (Table 3). Tolerable hazards have at least one element of the classification in the "tolerable" region.

For "unacceptable" hazards it is necessary to make improvements to mitigate the identified risks associated with the operation, at least to the level of "tolerable" risks. For "tolerable" risks the 'As Low As Reasonably Practical' (ALARP) principle must be abided with. This means, where reasonably possible, these risks must be reduced to the lowest practicable level, and safety management (e.g. monitoring) should be performed. "Negligible" hazards do not constitute a safety hazard to the operation.

The following safety hazards were identified:

Unacceptable hazards

- Crew: Inadequate crew training;
- Crew: Last minute change of navigation plan
- Crew: Timely arming of the GPS approach
- Charting: Confusion between GPS waypoints;
- Charting: Confusion between GPS and DME readings;

Tolerable hazards

GPS: GPS/RAIM availability;
Database: Database integrity;
Crew: Arming of the correct GPS approach
Crew/ATC: Intercept to the GPS approach inside the FAWP;
ATC: ATC Communication (cleared for waypoint that is not on the approach chart)
Database: Coding of waypoint attributes.

5.3 Hazard Classification

After the hazards classification some hazards are classified as “unacceptable”. A major unacceptable hazard is related to crew training aspects. GPS operations are a relative novelty to the pilot community. Tuition in GPS characteristics, failure modes and operational requirements has only recently been introduced to instrument-flight curricula. Furthermore, even though the equipment considered is TSO-approved the (type dependent) pilot interface can lead to “fingertrouble” resulting in an unacceptable aircraft trajectory. Also a large potential exists for pilots to have 'overconfidence' in the system.

Furthermore, the chance of a CFIT occurring because of ambiguous information published on the approach plate possibly confusing the pilot, is classified as an “unacceptable” hazard. This observation relates to the vertical descent profile, based on barometric altimetry that is performed by adhering to published altitudes during the final approach segment. Omission of a stepdown-waypoint can mitigate the risk of waypoint-confusion during the approach. Publishing a combined DME/GPS altitude table should be avoided, or topographic measures should be taken so that the correct information is unmistakably identified.

Tolerable risks were identified to be related to the GPS, the database, crew procedures and the relation to ATC. The ALARP principle incurs that proper training standards are adhered to by pilots that ATC controllers are informed about aircraft limitations on GPS NPAs and that database manufacturing remains an issue ruled by strict Quality Control Assurance and other methods ensuring data integrity such as Flight Inspection..

6 Conclusions

The approach of DFS, LBA and the contributing operators in the GPS evaluation towards the certification, the procedure design and the development of crew procedures for the GPS based non-precision approach operation, has been one of cautiousness. The decision to perform flight inspection of the new procedures, to publish the GPS procedures for authorised operators only, to develop the GPS/RAIM prediction tool and the development of specific Standard Operating Procedures by the operators, all clearly contributed to a successful and safe implementation of the GPS non-precision approach during the trial phase. The safety team concluded that all these measures are in fact *required* to maintain the current success of the implementation of the GPS procedure.

Each identified relative hazard has been classified, estimating the probability of occurrence and the effects of the hazards. As a result 11 hazards were identified. Of these a number of hazards have been classified as unacceptable, specifically related to crew training and charting.

For these unacceptable hazards, it is necessary to make improvements to mitigate the risks associated with the operation. For each hazard some potential risk reducing measures are proposed.

Without nullifying the potential safety benefits, the assessment shows that crew training is a critical issue when evaluating the GPS NPA operation (compared to the current NDB/DME procedure, with which pilots are well experienced). The current population of pilots especially from General Aviation is in general not yet trained for the use of GPS equipment for IFR operations.

The crew training should be focused on:

- Overall knowledge of the GPS characteristics and failure modes;
- The use of the GPS equipment installed in each specific aircraft (including rapid handling of waypoints);
- Avoiding 'overconfidence' in the GPS and the related equipment.

If no additional migration measures are introduced, it is expected that initially the introduction of GPS NPA operations may lead to a less safe operation compared to the current conventional NPA. At the same time it is recognised that over time pilots will get more experienced in the use of GPS and that the level of safety will rise above the safety of the conventional non-precision approach in due time.

With the application of safety management to ensure proper crew training, the team is confident that GPS NPA operations promise a safer operation than the current NPA operation.

7 Recommendations

Nine recommendations have been provided to improve the level of safety of the GPS based NPA.

1. It is recommended that approach plates are changed so that they do not show a combined distance-to-waypoint and local DME-distance versus altitude table for the final descent. Introducing typographic distinction between GPS information and DME information achieves the same goal.
2. It is recommended that the final approach segment is defined by two waypoints only (FAWP and MAWP).
3. It is recommended that a generic training syllabus is made available to the pilot community. Such a syllabus should also be available in German language.
4. It is recommended that DFS extends the policy adapted in the trial phase that GPS NPAs are available to authorized users only. Authorization should only be granted after an operator has demonstrated that some kind of GPS Implementation Plan demonstrating:
 - § Unit Installation and Operation in accordance with TSO C-129.
 - § Adequate SOPs for Normal and Abnormal situations.
 - § Adequate Training Program in force.For private operators pilot proficiency must be demonstrated to the authorities during the proficiency check.
5. It is recommended that database manufacturing remains subject to a Quality Assurance Program.

6. It is recommended that DFS extends the policy of flight-checking a procedure prior to publication.
7. It is recommended that the GPS/RAIM Prediction Tool for pre-flight planning remains in force.
8. It is recommended that the air traffic controller community is made aware of airborne limitations on GPS NPAs.
9. It is recommended that safety management is applied including adequate monitoring and active feedback by the key actors and verification that the recommendations are effectively implemented.

8 Reference documents

- RD- 1 "Safety Implications of GPS Non-precision Approach Landings", NLR-CR-99310, September 1999.
- RD- 2 Draft GNSS SARPs, ICAO GNSSP, April 1999.
- RD- 3 "Equipment Systems and Installations", Advisory Material Joint, AMJ 25.1309, Ch. 14, Joint Aviation Requirements, 1994.
- RD- 4 Guidance Material on Airworthiness Approval and Operational Criteria for the Use of Navigation Systems in European Airspace Designated for Basic RNAV Operations - JAA Leaflet No 2 rev. 1: AMJ 20X2
- RD- 5 JAA Interim Guidance Material on Airworthiness Approval and Operational Criteria for the Use of the NAVSTAR Global Positioning System, JAA Leaflet No 3.
- RD- 6 Bekanntmachung über die Musterzulassung und verwendung von GPS-Empfänger-systemen (German), LBA, NFL-II - 97/98
- RD- 7 'CFIT report , 'Flight Safety Foundation
- RD- 8 Procedures Air Navigation Services-Operations (PANS-OPS), ICAO Doc 8168.
- RD- 9 Anon., "Air navigation system safety assessment methodology", edition 0.4 working draft, Eurocontrol, 27 November 1996.
- RD- 10 Strategie für den Einsatz der satellitengestützten Navigation in der Zivilluftfahrt, 9. Dez. 1998.
- RD- 11 Accident risk assessment for advanced ATM, Henk Blom et al., Proc. second FAA/EUROCONTROL Air Traffic Management R&D Seminar, December 1st-4th 1998, in Orlando.
- RD- 12 CFIT Checklist, Flight Safety Foundation.
- RD- 13 GPS Risk Assessment, John Hopkins University, 29 January 1999.

Tables

Table 1: Definitions of severity categories according to JAR AMJ 25.1309 (qualitative).

Description	Definition
Catastrophic	Failure conditions, which would prevent continued safe flight and landing.
Hazardous	Failure conditions which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be: <ul style="list-style-type: none"> • A large reduction in safety margins or functional capabilities, • Physical distress or higher workload such that the flight crew cannot be relied upon to perform their task accurately or completely, or • Serious injury or fatal injury to a relatively small number of the occupants.
Major	Failure conditions which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example: <ul style="list-style-type: none"> • A significant reduction in safety margins or functional capabilities, • A significant increase in crew workload or in conditions impairing crew efficiency, or • Discomfort to occupants, possibly including injuries.
Minor	Failure conditions which would not significantly reduce aeroplane safety, and which involve crew actions that are well within their capabilities. Minor failure conditions may include, for example: <ul style="list-style-type: none"> • Slight reduction of safety margins, • Slight increase in crew workload, or • Some inconvenience to occupants.

Table 2: Definitions of probability levels according to JAR AMJ 25.1309 (qualitative).

Description	Estimate of Probability
Probable	Anticipated to occur one or more times during the entire operational life of each aeroplane ¹
Remote	Unlikely to occur to each aeroplane during its total operational life ¹ but which may occur several times when considering the total operational life of a number of aeroplanes of the type.
Extremely Remote	Unlikely to occur when considering the total operational life of all aeroplanes of the type, but nevertheless, has to be considered as being possible.
Extremely Improbable	So unlikely that they are not anticipated to occur during the entire operational life of all aeroplanes of one type.

Table 3: Hazard Classification matrix based on JAR AMJ 25.1309.

Probability Level	Severity			
	Catastrophic	Hazardous	Major	Minor
Probable	<i>Unacceptable</i>	<i>Unacceptable</i>	<i>Unacceptable</i>	<i>Tolerable</i>
Remote	<i>Unacceptable</i>	<i>Unacceptable</i>	<i>Tolerable</i>	<i>Negligible</i>
Extremely remote	<i>Unacceptable</i>	<i>Tolerable</i>	<i>Negligible</i>	<i>Negligible</i>
Extremely improbable	<i>Tolerable</i>	<i>Negligible</i>	<i>Negligible</i>	<i>Negligible</i>

Table 4: Reference NPA

Particular	Reference value/description	Comment
Obstacle clearance	Procedure according to PANS OPS design criteria	Additional DFS constraints apply
Approach segments considered	Initial, intermediate, final and missed approach. With or without radar vectors in initial and/or intermediate approach.	Arrival segment is not considered 'worst case'
Lateral guidance	NDB/DME is most common in German airspace	NDB shows worst error characteristics.
Vertical guidance	Stabilized approach path from FAF to threshold supplied using multiple DME fixes	DFS criterion
Aircraft approach category	Types A-D	Category E is not considered (military fighter).
Aircraft equipment - lateral indication	All types considered (TDI, RMI, HSI, and MAP)	All have particular hazards associated. Not clear what is 'worst case'.
Aircraft equipment - lateral guidance & control	All types considered (with or without AP and/or FD)	
Aircraft equipment - vertical indication	All types considered (with or without VNAV deviation indication)	
Aircraft equipment - vertical guidance & control	All types considered (with or without AP and/or FD)	



Table 5: Relative implications that possibly affect the safety of a non-precision approach as a consequence of introducing GPS to support the non-precision approach operation.

<i>Id</i>	<i>Short Description</i>	<i>Potential impact ¹</i>
1.	GPS distance information.	No impact
2.	Presentation of relevant navigation information.	Benefit
3.	Susceptibility to common weather phenomena.	Benefit
4.	Increased, and more consistent, position accuracy.	Benefit
5.	Go-around rate and execution	Benefit
6.	Availability	Hazard
7.	Database integrity	Hazard
8.	Coding of waypoint attributes	Hazard
9.	Area navigation	Benefit
10.	LNAV	Benefit
11.	VNAV	Benefit
12.	Crew training (required system knowledge and SOPs)	Hazard
13.	Pilot workload during the approach	Benefit
14.	Pilot situational awareness.	Benefit
15.	Arming of the correct GPS approach.	Hazard
16.	Timely arming of the GPS approach.	Hazard
17.	Interception of the GPS approach inside the FAWP.	Hazard
18.	Last-minute changes in navigation plan	Hazard
19.	R/T load	Benefit
20.	ATC communication: cleared to waypoint not in the active flightplan	Hazard
21.	Consistent procedure design	Benefit
22.	Confusion between GPS and DME readings	Hazard
23.	Confusion between GPS waypoints	Hazard