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Appendix F EXE-VLD-V4-100 Assessment of differences between approaches with ILS and GLS

Study is attached bellow.

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Appendix G EXE-VLD-V4-100 Cost Efficiency Study of GBAS Considering CAT II Approach Operation

G.1 Introduction

This appendix focuses on qualitative analysis of GBAS cost efficiency considering CAT II Approach Operation, CAT I equipment, operational experience and needs of ANSP and airlines contributing to WP2. Study addresses EXE-VLD-V4-100 demonstration objective OBJ-VLD-V4-031 and is based on historical records, simulation, and operational experience of study stakeholders, ANSP (DFS) and airlines (Lufthansa, Ryanair).

First, air navigation service provider view on the cost efficiency of GBAS CAT II operation using current equipment is provided focusing on capacity benefits on large airport. Then airlines view is provided focusing on specifics of both the hub operator and regional airport operator needs and so relates to large, medium, and small airport sub-operating environments.

From GBAS CAT II operation on CAT I equipment point of view, two categories of benefits can be distinguished in general. First, available GBAS CAT I benefit would now be attainable during LVC/CAT II as well. Second, the GBAS CAT II LVC operation specific benefits that are not available in CAT I conditions.

G.2 ANSP

G.2.1 Introduction

From an ANSP perspective, one of the advantages of GBAS CAT II operation introduction can possibly be an increase of runway capacity during Low Visibility Operations (LVO). During LVO the main parameter, limiting the landing capacity of an airport is the runway occupancy time. This is the time the aircraft needs on the runway to decelerate and to get clear of the runway up to a certain distance. This distance depends on whether the following aircraft is using ILS or GBAS as an approach guidance system. ILS protection zones have been defined, which are not necessary when using GBAS. Therefore, the runway occupancy time is reduced for aircraft on a GLS approach.

In order to evaluate the differences between GBAS and ILS and the potential benefits of GBAS during LVO, Fast Time Simulations have been performed by DFS for a scenario at Frankfurt airport using the AirTOp93 simulator tool.

The focus of the simulations was to analyse the consequences of a solely GBAS CAT II operations compared to a solely ILS CAT II operations with respect to the separation on final approach and the capacity of the selected runway 25R.

Fast Time Simulations however can only answer these questions when considering certain assumptions. Thus, the results are qualitative tendencies instead of quantitative facts. The following section provides an overview on setup and assumptions used for the simulations.

G.2.2 General Setup and Assumptions for Fast Time Simulation

Traffic scenario

- In order to achieve a high demand for RWY25R, a future prospect scenario with 100 movements per hour has been chosen.
- All aircraft are fed from virtual holdings into the TMA.
- Interaction between arrivals and departures have not been analysed. The scenario does not include departures.
- All aircraft (A380, B747, MD11) that are mandatory to land on the southern runway in Frankfurt are not included in the scenario.
- The scenario contains 412 approaches that are handled within the normal airport operation time (5AM -11PM). 22,8% of the approaching aircraft are wake turbulence category (WTC) 'Heavy'.
- The arrival procedures (UNOKO25N, ROLIS25N, KERAX25N) have been implemented into the simulation according to German AIP.
- A simplified model for Frankfurt airport ground infrastructure has been set up. It contains RWY25R with all turnoffs and taxiways.
- All aircraft (100%) are considered to be GLS capable.
- All WTC Medium aircraft vacate the RWY25R via exit P16 and all WTC Heavy aircraft vacate via exit P24.

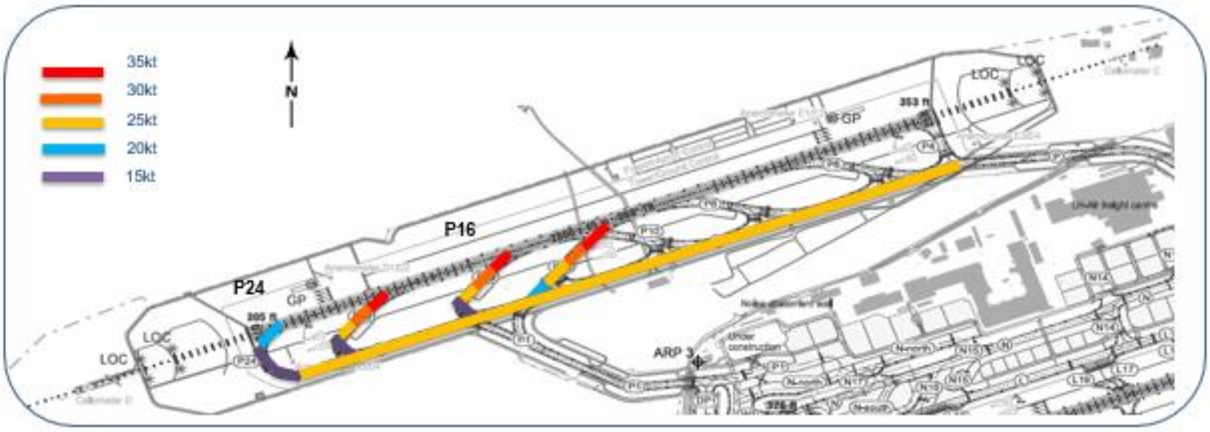


Figure 1: Runway 25R with color-coded taxi speeds used for the simulation

G.2.3 Definitions for low visibility operations with ILS

Obstacle Free Zone (OFZ):

- The OFZ shall be clear at the time the approaching aircraft is overhead the threshold.
- The OFZ is considered to be clear if the aircraft is 150m abeam the centreline (CAT II/III Stop).

Sensitive Area (SA) CAT II:

- For the Localizer SA the succeeding aircraft shall not be closer than 2NM when the preceding is turning off from centreline.
- For the Glidepath SA the succeeding aircraft shall not be closer than 2NM when the preceding is overhead the threshold.

If the above-mentioned conditions are not met, a missed approach procedure has to be flown.

Critical Area (CA) CAT II:

- For the Localizer CA the succeeding aircraft shall not be closer than 4NM when the preceding is turning off from centreline.
- For the Glidepath CA the succeeding aircraft shall not be closer than 15NM when the preceding is overhead the threshold.

If the above-mentioned conditions are not met, a missed approach procedure has to be flown.

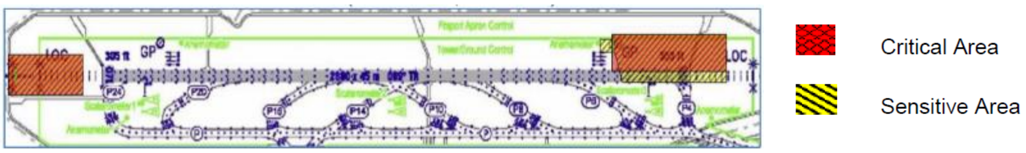


Figure 2: ILS protection zones RWY25R for Wake Turbulence Category (WTC) Light and Medium

For Light and Medium aircraft, the Sensitive Area in only relevant for the glidepath ➔ no aircraft allowed between 2NM final and threshold.

The Critical Area (LOC and GP) is outside the runway and does not need to be considered.

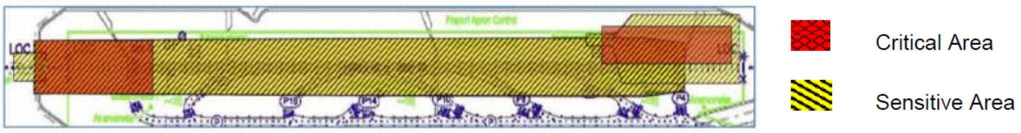


Figure 3: ILS protection zones RWY25R for Wake Turbulence Category (WTC) Heavy

No approaching aircraft is allowed between 2NM and threshold until the preceding aircraft is still inside the Sensitive Area (LOC and GP).

In the simulation Heavy aircraft are vacating via P24 and are inside the Critical Area of the Localizer thus, no aircraft allowed between 4NM final and threshold.

The Critical Area of the GP is not penetrated at any time.

Assumption for the simulation: the width of the CA/SA is equal the width of the OFZ (150m left and right of the centreline).

G.2.4 Definitions for Low Visibility Operations with GBAS

Obstacle Free Zone (OFZ):

- The OFZ shall be clear at the time the approaching aircraft is overhead the threshold.
- The OFZ is considered to be clear if the aircraft is 120m abeam the centreline (CAT II/III Stop).

Sensitive Area (SA) /Critical Area (CA) CAT II:

- No protection zones applicable for GBAS

Landing Clearance Line CAT II

- If an aircraft is inside the landing clearance line the succeeding aircraft shall not be closer than 0.6NM from threshold.

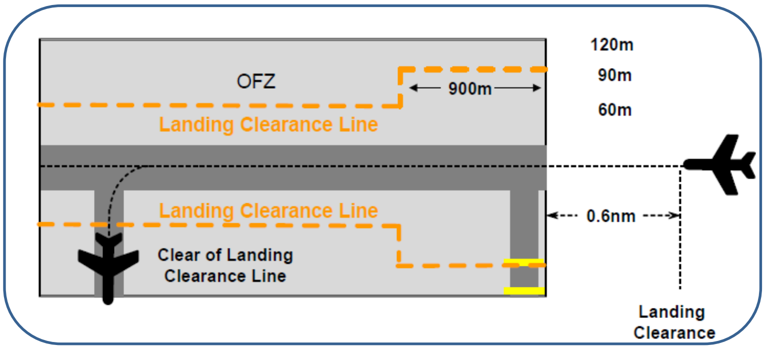


Figure 4: Landing Clearance Line [ICAO EUR Doc 013]

The landing clearance line has been modified to a parallel line with 90m distance from centreline for simplification purposes and in order to achieve conservative simulation results.

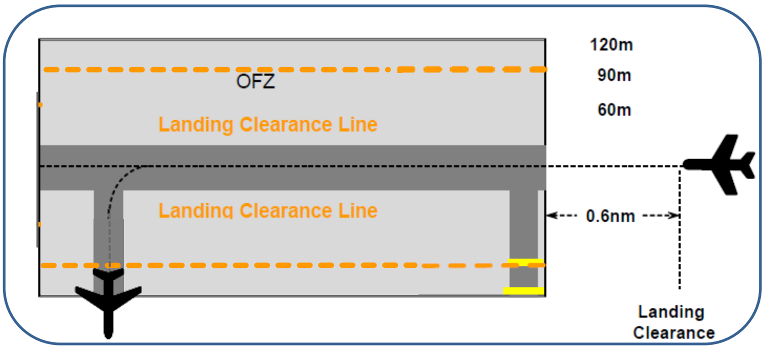


Figure 5: Modified Landing Clearance Line used for the simulation

G.2.5 Fast Time Simulation Results

ILS CAT II Procedure

Criteria for the ILS CAT II approach are:

- Until preceding WTC HEAVY aircraft is clear of OFZ: no aircraft allowed between 4NM final and threshold.
- Until preceding WTC MEDIUM aircraft is clear of OFZ: no aircraft allowed between 2NM final and threshold.

In order to comply with the above-mentioned criteria, the following optimal separation has been chosen:

WTC	**HEAVY**	**MEDIUM**
HEAVY	8NM	8NM
MEDIUM	8NM	5NM

Table 1: Separation for ILS case

The simulation shows that 100% of the WTC HEAVY aircraft fulfil the 4NM criteria. For the WTC MEDIUM aircraft, some (see red triangles in Figure 6) are closer than 2NM however 96% fulfil the criteria, therefore the separation has been maintained.

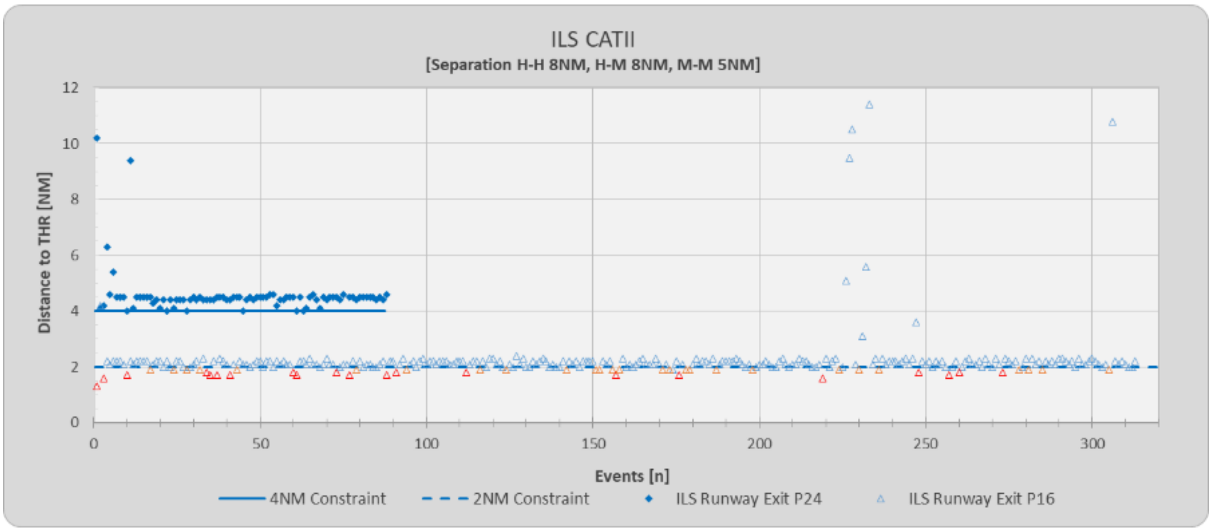


Figure 6: Distance to Threshold of the succeeding aircraft when preceding aircraft is clear of ILS protection zone (150m)

<u>GLS CAT II Procedure</u>

Criteria for the GLS CAT II approach are:

- Until preceding aircraft is clear of Landing Clearance Line: no aircraft allowed between 0.6NM final and threshold regardless of the WTC.

In order to comply with the above-mentioned criteria in a first step the following separation has been chosen:

WTC	**HEAVY**	**MEDIUM**
HEAVY	5NM	5NM
MEDIUM	5NM	5NM

Table 2: GBAS separation used

The simulation shows (Figure 7) that 100% of the aircraft fulfil the 0.6NM criteria. There is still room for further reduction of the separation.

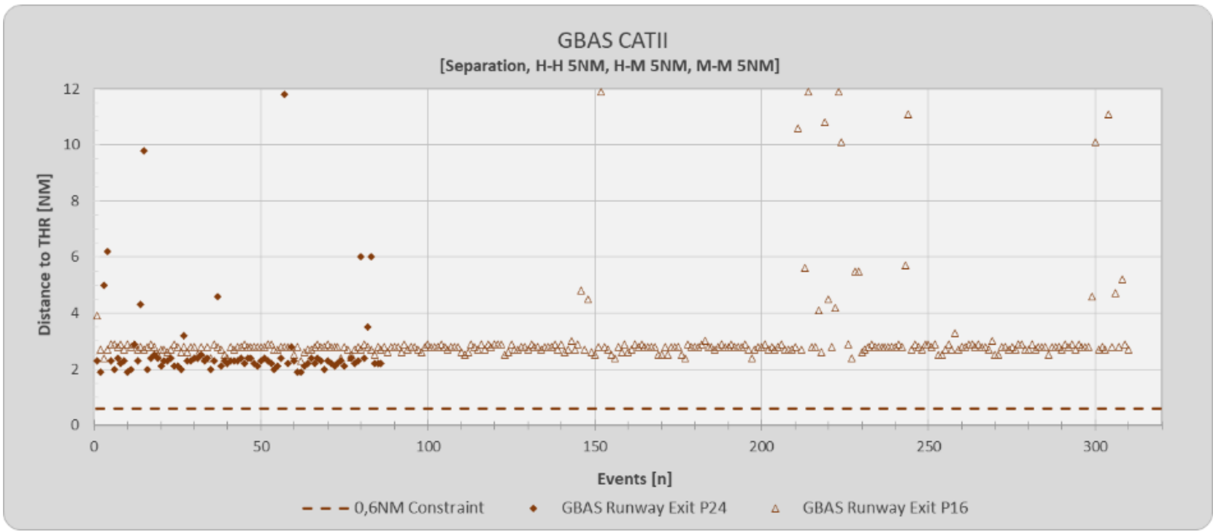


Figure 7: Distance to Threshold of the succeeding aircraft when preceding aircraft is clear of Landing Clearance Line (90m)

In the next step the separation has been reduce to WTC separation.

WTC	**HEAVY**	**MEDIUM**
HEAVY	4NM	5NM
MEDIUM	5NM	3NM

Table 3: Reduced separation to WTC

Following Figure 8 shows that all aircraft meet the 0.6NM criteria and therefore WTC separation is optimal.

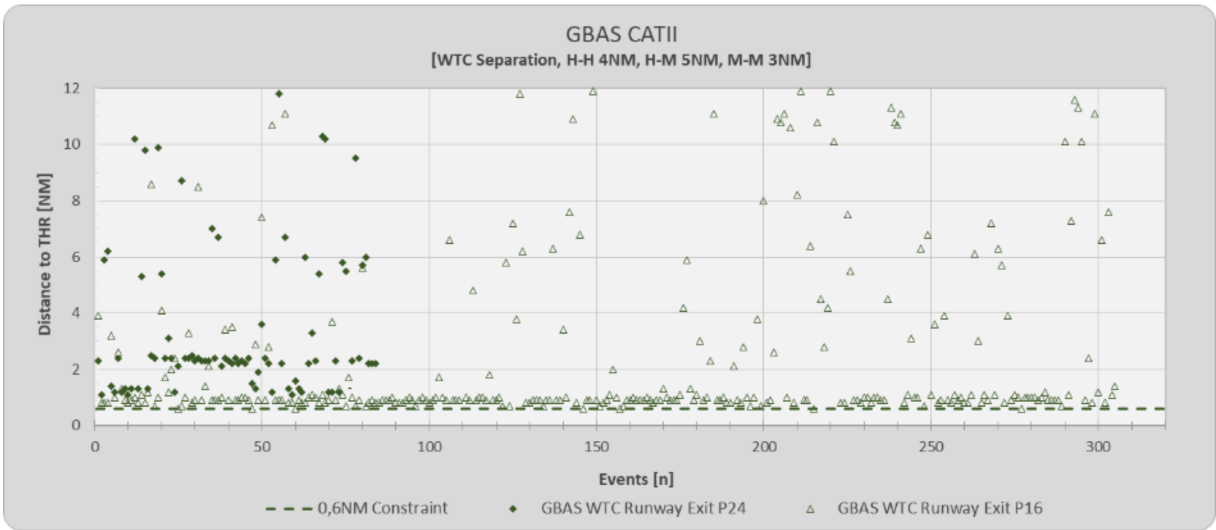


Figure 8: Distance to Threshold of the succeeding aircraft when preceding aircraft is clear of Landing Clearance Line (90m) applying WTC separation

In the next Figure 9 the overall demand (grey lines) is shown for certain hours of the day. The achievable capacity with ILS (blue line) cannot satisfy the demand. When applying 5NM separation with GBAS (brown line) the capacity can be increased however, it is still below the demand. Further reduction of the aircraft spacing to minimum allowable WTC separation (green line) finally leads to a capacity that can satisfy the demand.

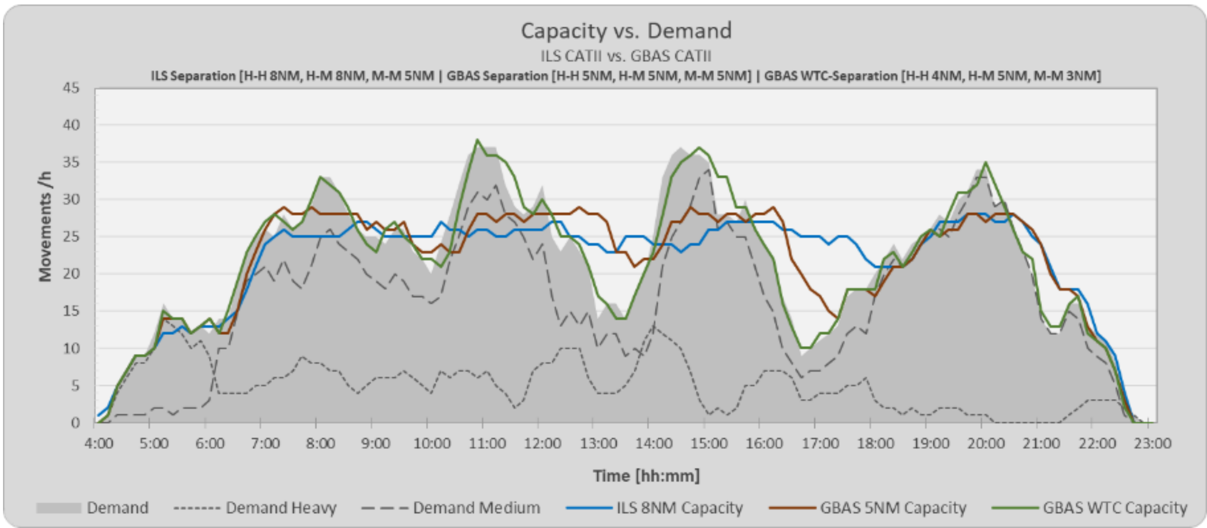


Figure 9: Actual capacity versus demand

G.2.6 Procedural Methods of Fast Time Simulations

Identified potential benefits of the GLS procedures:

- Landing clearance can be issued at a later point in time (reduced distance to 0.6NM) due to missing Critical- and Sensitive Areas.
- When applying the Landing Clearance Line, the preceding aircraft vacates the runway earlier. This effect leads to a greater distance to threshold for the succeeding aircraft and can be used to reduce separation.

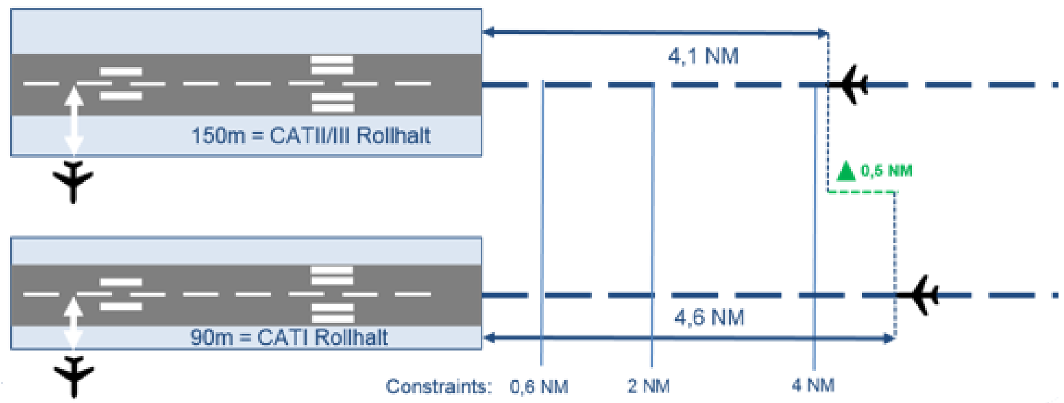


Figure 10: Distance gain when using Landing Clearance Line concept

The simulations have been performed considering the above-mentioned assumptions and definitions. Several runs with iterative steps have been performed in order to find the optimal separation. The following chapter provides an overview on the results.

G.2.7 Conclusions

The results of the simulations indicate that an increase of capacity runway is most likely when using GLS CAT II approach procedures instead of ILS CAT II. The reasons for this increase of capacity are the missing protection zones for GBAS and the Landing Clearance Line concept that allows the aircrafts to be clear of the runway at an earlier point of time. The capacity gain depends on the number of aircraft WTC HEAVY that cause most of the restrictions when using ILS. In addition, the taxi speeds of the aircrafts when vacating the runway is relevant for the results.

The simulations have been performed with various assumptions and simplifications. The results have a qualitative character only. One of the major parameters for the simulations is the GBAS equipage rate that was set to 100 percent. Currently the actual GBAS equipage at Frankfurt is around 8 percent and therefore it would not be possible to operate one runway as a GBAS Only runway today. Further investigations and simulations with a more detailed setup should be performed to evaluate the possible benefit e.g. for smaller numbers of equipage rate.

Nevertheless, the presented results of this report demonstrate that there is a positive tendency for greater capacity when using GLS instead ILS in low visibility conditions. With use of GAST C ground station and airborne equipment for CAT II operations, increased capacity would bring ANSPs, Airports and Airlines higher cost efficiency.

G.3 Airlines

G.3.1 Operating Hub Airports

Significant Lufthansa operations are done to HUB airports, therefore focus of this chapter is on identification and analysis of benefits in utilization of GBAS Landing System (GLS) instead of Instrument landing System (ILS) at the specific example of large hub airport.

Among other things, a high density of air traffic characterizes Frankfurt International Airport. Up to 1400 take-off and landings can be counted at Frankfurt airport per day. The high density of air traffic has implications for the utilization of possible landing systems, landing routes and landing procedures. These varied landing systems, landing routes and landing procedures can cause differences with regard to efficiency and environmental impact (e.g. fuel burn, CO2 emission, noise level).

Most of the approaches at Frankfurt Airport are currently performed on the base of the Instrument Landing System (ILS). These approaches require a level flight of several nautical miles (NM) before flight crews are allowed to initiate the further descent in an altitude of 5000 or 4000ft.

In order to reduce the environmental impact (e.g. CO2 emission, noise level) and increase flight efficiency (e.g. reduced fuel burn) during an approach a late continuous descent from a high altitude is required.

Instead of an ILS approach, flight crews can also approach with GBAS Landing System (GLS) at Frankfurt Airport if the aircraft is equipped for corresponding GLS approaches and the flight crew receives appropriate clearance from ATC tower.

GLS approaches carry the advantage that GLS Glideslope certification is already available up to 23 nautical miles. As a consequence of this, ATC towers can clear an approach from an altitude up to 7000ft. This is 2000 to 3000ft higher in comparison to the ILS approach.

Simulator and flight data analysis with a Boeing 747-8 has shown fuel savings of approximately 20kg per approach that started from 7000ft (instead of a level flight in 4000ft before commencing the ILS approach). A real Airbus A380 GLS approach from 7000ft to Frankfurt airport confirmed the fuel saving calculation from simulator. Considering SESAR ERM methodology [88] where direct link between fuel burn and the amount of CO2 produced is provided (i.e. 3.15 times the mass of fuel burnt), fuel savings result in 63 kg savings of CO2.

A fuel saving analysis for GLS approaches with regard to short-range aircraft (e.g. Airbus A320) could not be accomplished until now. A first estimate (without confirmation) is a fuel saving of approximately 8-10 kg per GLS approach with a short-range aircraft.

The percentage of GLS approaches from 7000ft at Frankfurt airport is limited due to the high density of air traffic and a mixed traffic situation. The DFS expect that currently 10% of Lufthansa approaches at Frankfurt airport with a long-range aircraft can receive a clearance to commence the approach out of 7000ft.

Lufthansa A380 and 747-8 aircraft are equipped for GLS approaches until now. If you calculate 15 to 20 landings per day with above-mentioned Lufthansa aircraft and you consider the 10% DFS clearance, one or two Lufthansa aircraft could perform a GLS approach per day at Frankfurt airport with a fuel saving of app. 40kg. With higher aircraft GLS equipage rate, more clearances could be allowed by DFS which would imply higher fuel and CO2 savings.

If the GBAS landing system (GLS) would be certified for CAT II and CAT III operation, too, these savings could be achieved during Low Visibility Conditions as well. In the case of certified GLS CAT II operation with GAST C equipment, currently available GBAS airborne equipment for CAT I operation would be sufficient to gain these benefits in LVC down to CAT II minimums. Since no protection and safety areas for GLS approaches are required, a higher throughput of two to three aircraft per hour (during LVO) could be achieved. This higher throughput could avoid delays, holdings, diversions, and cancellations which would imply lower cost for an airline. Both the fuel savings due to higher altitude of approach start, and reduction of delays, holdings, diversions, and cancellations, are achievable with current airborne GBAS CAT I equipment which implies overall good cost efficiency for both non-LVC and LVC conditions.

G.3.2 Operating Regional Airports

Different aspects of GBAS/CAT II operation cost efficiency from regional airport operator perspective were studied by Ryanair. Provided view on the cost efficiency of the GBAS CAT II solution on CAT I equipment is based on Ryanair extensive experience with flight operation to regional airports, data analysis and specific examples with identified cost efficiency prospects of GBAS CAT II on CAT I equipment solution operational deployment.

GLS CAT II approaches will be available without the cost of extra aircraft equipment. Considering Ryanair fleet, approximately 42 aircraft are equipped with GBAS and all new arriving aircraft will have GBAS fitted with over 100 B737 Max aircraft ordered with options for a significant number more. No retrofit of the existing fleet with GBAS planned at this time. Depending on B737 Max deliveries fleet of approximately 142 GBAS equipped aircraft over the next few years would benefit from GBAS CAT II operation introduction without need of any extra equipment to carry out which brings cost benefit.

GLS CAT II approaches will be available without additional training costs. Often when new procedures or new equipment are introduced into the aircraft crews need to first do a training programme in the simulator before they can use the procedure/equipment. In the case of large regional airport operator like Ryanair, 5000 pilots would need to go through a simulator programme. This would include the cost of simulators, training instructors, travel, and hotels. There would also be a loss productivity from pilots adding to further cost. GBAS is so similar to ILS that operator can use the same procedures and same SOP call as ILS approaches. This means operator does not need additional training in simulators and the significant cost that entails. Each hour in the simulator costs about 450 euro an hour. A 2-hour training session would cost 900 euros and to train all crews, 2500 sessions in total would be needed at a cost of over 2.25 million euro. Accommodation costs and other training expenses would cost about ¾ million euro so the training costs savings would be 3 million euro.

GLS CAT II approaches should become available to smaller airports that currently find ILS CAT II approach equipment prohibitively expensive. Operators like Ryanair fly to many smaller regional airports, typically with ILS one side and non-precision approach on the other. GLS CAT II operation gives regional airport operator such as Ryanair the opportunity to operate CAT II approaches to both runways. This has a cost benefit to the airline with far less diversions from regional airports. Diversions can be very expensive, passengers have to be normally bussed to and from the original destination. The aircraft is not doing its planned rotation leading to follow on delays and in the worst-case cancellations. Airline customers are also greatly in inconvenienced and may be slow to travel with the airline again. GBAS CAT II approaches would help mitigate against this.

In this study, Ryanair conducted a detailed analysis of diversions in 2018. In 2018 this year Ryanair had 761 diversions. About 50% were due to the weather being below minima at the destination (Non-precision or CAT 1). GLS CAT II approach would have mostly allowed the aircraft to land. Each diversion costs about 75,000 euro. This includes the cost of EU Regulation 261/2004 (EU law relating to flight delay compensation), handling, coaches, airport charges, fuel etc. This costs about 28 million a year. The cost of having aircraft out of position is difficult to quantify, if a flight is diverted the follow-on flights either need to be completed by a spare aircraft, a different line of flying needs to be disrupted, the flight is delayed and completed by the delayed aircraft or the flight is cancelled. Ryanair estimate the cost to the operation of about 12 million euro a year so the total saving would be in excess of 40 million a year to Ryanair.

Impact of low visibility condition can be well described on analysis of Ryanair flights in Poland. Ryanair has recently rapidly expanded its operation in Poland setting up a Polish airline called Ryanair Sun (Buzz) with further expansion planned over the next few years. However, many of the regional Polish airports have traditionally had precision approach to one end and non-precision the other end. Also, Poland suffers from fog particularly in autumn and spring and the fog can affect large areas of the country. Considering approach types available as Ryanair is expanding as well in France where opened first French bases, Bordeaux, and Toulouse in 2019, like in Poland many French regional airports have a precision approach one end and non-precision the other. Ryanair see GBAS CAT II being particularly useful in Poland considering character of weather systems and number of flights to Polish regional airports. Due to the nature of fog in Poland affecting large areas of the country the aircraft often need to divert to airports that are a considerable distance away. While Ryanair average cost of diversion described earlier is about 75,000 euro, in Poland it can be higher due to the distances to bus passengers and the time spent waiting for passengers to arrive at the aircraft. In Poland, Ryanair estimates diversion costs closer to 100,000 per flight. With GBAS CAT II allowing aircraft to land in poor weather conditions, significant cost savings are thus expected.

The new Bremen RNP to GLS procedures are without level segments and allow airlines to fly a continuous descent approach (CDA). A CDA has significant benefits when it comes to fuel burn and CO2 emissions, lower costs, and lower CO2 emissions with GBAS designed CDA approaches are expected. With better routings, CDA significantly reduces noise pollution, hence being able not to overfly noise sensitive areas.

Leveraging PBN approaches to shorter final approach segments as low as 4 NM enabled by GBAS give the benefit of shorted routings, fuel, and CO2 emissions savings with significant cost benefit impact. Operators may also be able to avoid noise sensitive areas on approach. Some airports have restrictions on opening times due noise on departing/arriving aircraft. Better designed approaches may allow airports to stay open longer. This would have a cost benefit as no diversion is needed in the case of flight delay and could get higher productivity from the aircraft. In terms of fuel savings in approach, Ryanair saves for every 10 NM approximately 100 kg of fuel. Considering that Ryanair operates about 2000 flights per day, if overall shorter PBN procedures by only 1 NM in average are available for approach compared to currently flown approaches, this would bring 20 tonnes a day or 7,300 tonnes a year or fuel savings. At an example price of 900 euro a tonne this would bring cost savings of 18,000 euro a day or 6.5 million euro a year.

Appendix H EXE-VLD-V4-100 RNP to GLS CAT I Approach Charts (EDDW)

The new RNP to GLS procedures that were designed by DFS in the frame of AAL2 project and published in July 2019 AIRAC cycle can be found in this appendix.

LUFTFAHRTHANDBUCH DEUTSCHLAND
AIP GERMANY

AD 2 EDDW 4-7-7
Effective: 18 JUL 2019

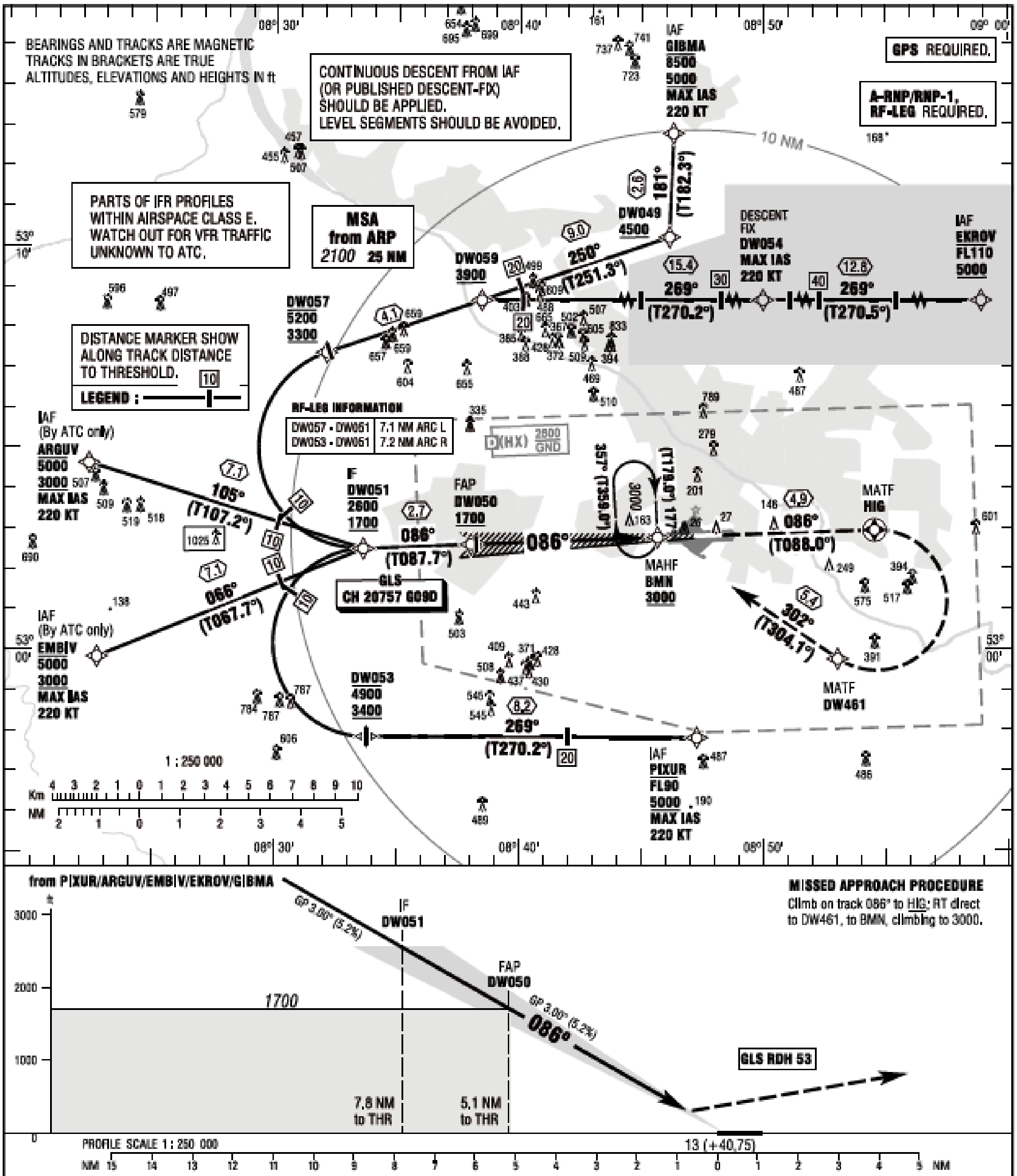
INSTRUMENT APPROACH CHART - ICAO

VAR 2° E

ELEV 14
OCH RELATED TO THR 09 ELEV 13

BREMEN ATIS	132,375	BREMEN TOWER	120,325
BREMEN RADAR	124,800	BREMEN GROUND	121,750

BREMEN
GLS Y
RWY 09



OCA (OCH)	A	B	C	D
GLS CAT I	158 (145)	167 (154)	177 (164)	187 (174)

DIST THR / RW09	9	8	7	6	5	4	3	2	1
ALTITUDE	2940	2620	2300	1980	1660	1340	1030	710	390

GS	kt	80	100	120	140	160	180
DW050 - THR (5.1 NM)	MIN:SEC	3:50	3:04	2:33	2:11	1:55	1:42
Rate of descent (5,2%)	ft / MIN	420	530	640	740	850	960

Correction: New procedure.

AIRAC AMDT 08/19

INITIAL, INTERMEDIATE AND MISSED APPROACH

Approach Segment	Recom-mended Path Ter-minator	Waypoint Identifier	Coordinates	Fly Over	(True Track°) MAG Track°	Distance (NM)	Turn Direc-tion	Altitude (ft) / Flight Level	Speed Limit (kt IAS)	Vertical Path Angle (°)/ TCH (ft)	Recom-mended Altitudes for CDO	NAV-Specification	Remark
Initial APCH from PIXUR	IF	PIXUR	N 52 57 48.94 E 008 47 13.82	-	-	-	-	FL090- A5000+	220-	-	A7453	RNP-1/A-RNP RF-Leg required	-
	TF	DW053	N 52 57 50.30 E 008 33 41.04	-	(T270.2) 269	8.2	-	A4900- A3400+	-	3.0	A4845	RNP-1/A-RNP RF-Leg required	-
	RF	DW051	N 53 02 29.49 E 008 33 32.88	-	-	7.2	R	A2600- A1700+	-	3.0	A2547	RNP-1/A-RNP RF-Leg required	ARC Center: DW052 N 53 00 09.85 E 008 33 42.22 ARC Radius: 2.33 NM
	TF	DW050	N 53 02 35.84 E 008 37 57.06	-	(T067.7) 066	2.7	-	A1700+	-	3.0	A1700	RNP-1/A-RNP RF-Leg required	FAF for GLS FAS
Initial APCH from EMBIV	IF	EMBIV	N 52 59 48.33 E 008 22 37.26	-	-	-	-	A5000- A3000+	220-	-	A4815	RNP-1/A-RNP	-
	TF	DW051	N 53 02 29.49 E 008 33 32.88	-	(T067.7) 066	7.1	-	A2600- A1700+	-	3.0	A2547	RNP-1/A-RNP	-
	TF	DW050	N 53 02 35.84 E 008 37 57.06	-	(T067.7) 066	2.7	-	A1700+	-	3.0	A1700	RNP-1/A-RNP	FAF for GLS FAS
Initial APCH from ARGUV	IF	ARGUV	N 53 04 36.37 E 008 22 16.38	-	-	-	-	A5000- A3000+	220-	-	A4814	RNP-1/A-RNP	-
	TF	DW051	N 53 02 29.49 E 008 33 32.88	-	(T107.2) 105	7.1	-	A2600- A1700+	-	3.0	A2547	RNP-1/A-RNP	-
	TF	DW050	N 53 02 35.84 E 008 37 57.06	-	(T067.7) 066	2.7	-	A1700+	-	3.0	A1700	RNP-1/A-RNP	FAF for GLS FAS
Initial APCH from GIBMA	IF	GIBMA	N 53 12 46.94 E 008 46 17.42	-	-	-	-	A8500- A5000+	220-	-	A8488	RNP-1/A-RNP RF-Leg required	-
	TF	DW049	N 53 10 12.57 E 008 46 07.10	-	(T182.3) 181	2.6	-	A4500+	-	3.0	A7668	RNP-1/A-RNP RF-Leg required	-
	TF	DW057	N 53 07 20.87 E 008 32 01.70	-	(T251.3) 250	9.0	-	A5200- A3300+	-	3.0	A4817	RNP-1/A-RNP RF-Leg required	-
	RF	DW051	N 53 02 29.49 E 008 33 32.88	-	-	7.1	L	A2600- A1700+	-	3.0	A2547	RNP-1/A-RNP RF-Leg required	ARC Center: DW058 N 53 04 59.21 E 008 33 22.85 ARC Radius: 2.50 NM
	TF	DW050	N 53 02 35.84 E 008 37 57.06	-	(T067.7) 066	2.7	-	A1700+	-	3.0	A1700	RNP-1/A-RNP RF-Leg required	FAF for GLS FAS
Initial APCH from EKROV	IF	EKROV	N 53 08 34.09 E 009 25 06.20	-	-	-	-	FL110- A5000+	-	-	-	RNP-1/A-RNP RF-Leg required	-
	TF	DW054	N 53 08 38.47 E 009 03 55.66	-	(T270.5) 269	12.8	-	-	220-	-	A11000	RNP-1/A-RNP RF-Leg required	Descent fix for CDO
	TF	DW059	N 53 08 38.82 E 008 38 24.27	-	(T270.2) 269	15.4	-	A3900+	-	3.0	A6108	RNP-1/A-RNP RF-Leg required	-
	TF	DW057	N 53 07 20.87 E 008 32 01.70	-	(T251.3) 250	4.1	-	A5200- A3300+	-	3.0	A4817	RNP-1/A-RNP RF-Leg required	-
	RF	DW051	N 53 02 29.49 E 008 33 32.88	-	-	7.1	L	A2600- A1700+	-	3.0	A2547	RNP-1/A-RNP RF-Leg required	ARC Center: DW058 N 53 04 59.21 E 008 33 22.85 ARC Radius: 2.50 NM
	TF	DW050	N 53 02 35.84 E 008 37 57.06	-	(T067.7) 066	2.7	-	A1700+	-	3.0	A1700	RNP-1/A-RNP RF-Leg required	FAF for GLS FAS
Missed Approach	-	RW09	N 53 02 47.67 E 008 46 28.03	-	(T067.9) 066	-	-	-	-	-		RNP APCH	-
	CF	HIG	N 53 02 57.61 E008 54 31.59	Y	(T068.0) 066	4.9	-	-	-	-		RNP APCH	-
	DF	DW461	N 52 59 46.14 E 008 53 00.60	-	-	-	R	-	-	-		RNP APCH	-
	TF	BMN	N 53 02 46.51 E 008 45 37.61	-	(T304.1) 302	5.4	-	@A3000	-	-		RNP APCH	-

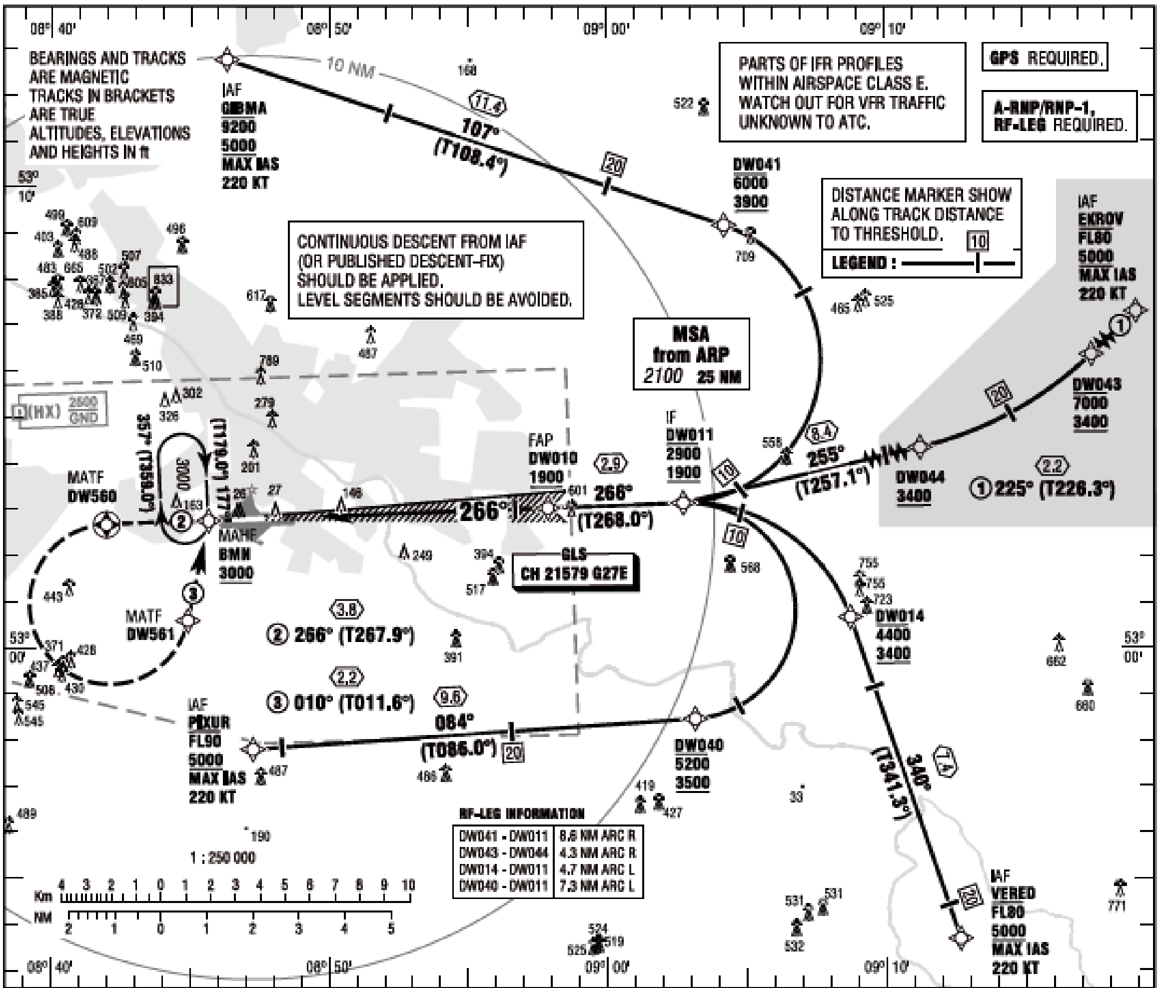
HOLDING IDENTIFICATION

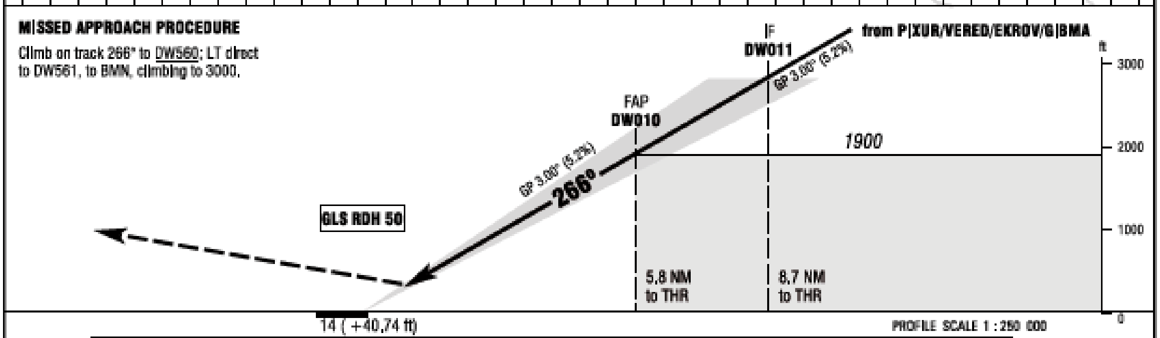
Recom-mended Path Ter-minator	Holding Fix	Coordinates	Inbound (True Track°) MAG Track°	Max Speed (kt IAS)	Minimum/Maximum Holding Altitude (ft) or Flight Level	Time / Distance outbound	Turn Direction
HM	BMN	N 53 02 46.51 E 008 45 37.61	(T179.0)177	230	A3000+/FL100-	1 MIN	RT

LUFTFAHRTHANDBUCH DEUTSCHLAND
AIP GERMANY

AD 2 EDDW 4-7-5
Effective: 18 JUL 2019

INSTRUMENT APPROACH CHART - ICAO	VAR 2° E	ELEV 14 OCH RELATED TO THR 27 ELEV 14	BREMEN ATIS 132,375 BREMEN RADAR 124,800	BREMEN TOWER 120,325 BREMEN GROUND 121,750	BREMEN GLS Y RWY 27





OCA (OCH)	A	B	C	D
GLS CAT I	159 (145)	169 (155)	179 (165)	189 (175)

DME THR / RW27	1	2	3	4	5	6	7	8	9
ALTITUDE	390	710	1020	1340	1660	1980	2300	2620	2930

GS	kt	80	100	120	140	160	180
DW010- THR (5,8 NM)	MIN:SEC	4:21	3:29	2:54	2:29	2:11	1:56
Rate of descent (5,2%)	ft / MIN	420	530	640	740	850	960

Correction: New procedure.

AIRAC AMDT 08/19

INITIAL, INTERMEDIATE AND MISSED APPROACH													
Approach Segment	Recom-mended Path Ter-minator	Waypoint Identifier	Coordinates	Fly Over	(True Track°) MAG Track°	Distance (NM)	Turn Direc-tion	Altitude (ft) / Flight Level	Speed Limit (kt IAS)	Vertical Path Angle (°) / TCH (ft)	Recom-mended Altitudes for CDO	NAV-Specification	Remark
Initial APCH from PIXUR	IF	PIXUR	N 52 57 48.94 E 008 47 13.82	-	-	-	-	FL090-A5000+	220-	-	A8226	RNP-1/A-RNP RF-Leg required	-
	TF	DW040	N 52 58 28.00 E 009 03 07.69	-	(T086.0) 084	9.6	-	A5200-A3500+	-	3.0	A5160	RNP-1/A-RNP RF-Leg required	-
	RF	DW011	N 53 03 09.03 E 009 02 43.06	-	-	7.3	L	A2900-A1900+	-	3.0	A2837	RNP-1/A-RNP RF-Leg required	ARC Center: DW020 N 53 00 48.38 E 009 02 51.12 ARC Radius: 2.35 NM
	TF	DW010	N 53 03 02.85 E 008 57 50.63	-	(T268.0) 266	2.9	-	A1900+	-	3.0	A1900	RNP-1/A-RNP RF-Leg required	FAF for GLS FAS
Initial APCH from GIBMA	IF	GIBMA	N 53 12 46.94 E 008 46 17.42	-	-	-	-	A9200-A5000+	220-	-	A9199	RNP-1/A-RNP RF-Leg required	-
	TF	DW041	N 53 09 10.47 E 009 04 12.62	-	(T108.4) 107	11.4	-	A6000-A3900+	-	3.0	A5580	RNP-1/A-RNP RF-Leg required	-
	RF	DW011	N 53 03 09.03 E 009 02 43.06	-	-	8.6	R	A2900-A1900+	-	3.0	A2837	RNP-1/A-RNP RF-Leg required	ARC Center: DW042 N 53 06 14.72 E 009 02 32.40 ARC Radius: 3.10 NM
	TF	DW010	N 53 03 02.85 E 008 57 50.63	-	(T268.0) 266	2.9	-	A1900+	-	3.0	A1900	RNP-1/A-RNP RF-Leg required	FAF for GLS FAS
Initial APCH from EKROV	IF	EKROV	N 53 08 34.09 E 009 25 08.20	-	-	-	-	FL060-A5000+	220-	-	A7585	RNP-1/A-RNP RF-Leg required	-
	TF	DW043	N 53 07 02.16 E 009 22 28.32	-	(T226.3) 225	2.2	-	A7000-A3400+	-	-	A6878	RNP-1/A-RNP RF-Leg required	-
	RF	DW044	N 53 05 02.14 E 009 16 16.67	-	-	4.3	R	A3400+	-	3.0	A5509	RNP-1/A-RNP RF-Leg required	ARC Center: DW045 N 53 12 49.46 E 009 13 18.26 ARC Radius: 8.00 NM
	TF	DW011	N 53 03 09.03 E 009 02 43.06	-	(T257.1) 255	8.4	-	A2900-A1900+	-	3.0	A2837	RNP-1/A-RNP RF-Leg required	-
	TF	DW010	N 53 03 02.85 E 008 57 50.63	-	(T268.0) 266	2.9	-	A1900+	-	3.0	A1900	RNP-1/A-RNP RF-Leg required	FAF for GLS FAS
Initial APCH from VERED	IF	VERED	N 52 53 40.71 E 009 12 38.10	-	-	-	-	FL060-A5000+	220-	-	A6668	RNP-1/A-RNP RF-Leg required	-
	TF	DW014	N 53 00 39.73 E 009 08 43.26	-	(T341.3) 340	7.4	-	A4400-A3400+	-	3.0	A4338	RNP-1/A-RNP RF-Leg required	-
	RF	DW011	N 53 03 09.03 E 009 02 43.06	-	-	4.7	L	A2900-A1900+	-	3.0	A2837	RNP-1/A-RNP RF-Leg required	ARC Center: DW015 N 52 59 27.40 E 009 02 55.75 ARC Radius: 3.70 NM
	TF	DW010	N 53 03 02.85 E 008 57 50.63	-	(T268.0) 266	2.9	-	A1900+	-	3.0	A1900	RNP-1/A-RNP RF-Leg required	FAF for GLS FAS
Missed Approach	-	RW27	N 53 02 50.15 E 008 48 17.46	-	(T268.0) 266	-	-	-	-	-		RNP APCH	-
	CF	DW560	N 53 02 41.41 E 008 41 57.51	Y	(T267.9) 266	3.8	-	-	-	-		RNP APCH	-
	DF	DW561	N 53 00 36.44 E 008 44 53.35	-	-	-	L	-	-	-		RNP APCH	-
	TF	BMN	N 53 02 46.51 E 008 45 37.61	-	(T011.6) 010	2.2	-	@A3000	-	-		RNP APCH	-

HOLDING IDENTIFICATION							
Recom-mended Path Ter-minator	Holding Fix	Coordinates	Inbound (True Track°) MAG Track°	Max Speed (kt IAS)	Minimum/Maximum Holding Altitude (ft) or Flight Level	Time / Distance outbound	Turn Direction
HM	BMN	N 53 02 46.51 E 008 45 37.61	(T179.0)177	230	A3000+/FL100-	1 MIN	RT

Published charts:

ED_AD_2_EDDW_4-7-8_en_2019-07-18.p
ED_AD_2_EDDW_4-7-7_en_2019-07-18.p
ED_AD_2_EDDW_4-7-6_en_2019-07-18.p
ED_AD_2_EDDW_4-7-5_en_2019-07-18.p

Appendix I EXE-VLD-V4-100 Compliance Matrix to SESAR Solution #55

The technical solution under WP2 demonstrate GLS CAT II operation on GAST-C/CAT I station that allows to utilize CAT I equipment to support CAT II operation. Therefore, both airborne and ground system does not need to comply with all Solution #55 OSED requirements for CAT II/III GBAS GAST D operation. As GLS CAT II on GAST-C/CAT I equipment does not target CAT III operation, it does not require GAST D airborne and ground equipment.

Identifier	Requirement	Com-pliance	Remarks
REQ-06.08.05-OSED-GBAS.0010	The aircraft's on-board GLS function to land shall be able to operate with any Cat II/III GLS ground station compliant with ICAO Annex 10 GAST D.	No	The aircraft should only be capable to operate with GAST C ground station on GLS approach down to CAT II minimums. GAST D capability is not needed.
REQ-06.08.05-OSED-GBAS.0020	The ILS on-board design shall be the reference for the on-board GLS CAT II/III approach selection, display, guidance, warning, considering the ILS look-alike concept.	Partly	Only GLS CAT II is applicable.
REQ-06.08.05-OSED-GBAS.0030	The GLS Cat II/III aircraft precision approach capability shall provide the flight air crew with accurate and timely information on GLS service degradation and failures.	No	GAST D service level downgrade does not apply.
REQ-06.08.05-OSED-GBAS.0040	The aircraft shall be capable to perform guided take-off based on GLS lateral guidance, similar to the existing ILS based take-off.	No	Guided take-off is not within the scope of CAT II operation on GBAS GAST C station.
REQ-06.08.05-OSED-GBAS.0050	The GBAS ground system shall be able to provide for GBAS CAT II/III precision approach capability to any GLS CAT III capable aircraft, as defined in ICAO Annex 10 GAST D SARPS.	No	The GBAS ground system shall support approach operation down to CAT II minimums, aircraft and operators needs to be approved for this operation. Aircraft does not have to be GBAS CAT III capable.

REQ-06.08.05-OSED-GBAS.0060	The GBAS GAST-D ground station shall provide accurate and timely information on GBAS service degradation and failures to the relevant maintenance of ATC units.	Partly	Information is provided, however timing requirement of 1.5 seconds is not met, however is mitigated through airborne (CAT I system supports 3s).
REQ-06.08.05-OSED-GBAS.0070	The GBAS GAST-D ground station shall provide timely information on the GBAS service availability for each runway end for which an approach is provided.	Partly	Information is provided, however timing requirement of 1.5 seconds is not met, however is mitigated through airborne (CAT I system supports 3s).
REQ-06.08.05-OSED-GBAS.0080	The GBAS ground stations shall provide for guided take-off service similar to the existing ILS based take-off.	n/a	Guided take-off service is currently not used with GBAS in Germany.
REQ-06.08.05-OSED-GBAS.0090	The Flight Crew shall be able to perform precision approaches in Low Visibility Conditions using GBAS CAT II/III (based on GPS L1).	Partly	GBAS CAT II approach and GAST C Ground Station needed only.
REQ-06.08.05-OSED-GBAS.0100	At any time during the flight, the crew shall be aware of aircraft GLS Cat II/III approach capabilities if equipment availability and/or navigation performance is downgraded	Partly	Only GBAS CAT II applicable. ATC provides to the crew information about GBAS service level downgrade. Availability of CAT II approach is provided through standard means (AIP, ATIS, ..).
REQ-06.08.05-OSED-GBAS.0110	The flight crew shall be able to perform a safe operation in case of provision of GBAS CAT II landing clearance by ATC as late as 1 NM before touchdown.	Yes	
REQ-06.08.05-OSED-GBAS.0120	When both ILS and GBAS procedures are available, the flight crew shall communicate to ATC the preferred approach type	Yes	

REQ-06.08.05-OSED-GBAS.0130	The Tower Runway Controller shall be able to use the landing clearance line (displayed in the A-SMGCS) for aircraft vacating the runway in front of a GBAS arrival aircraft.	n/a	A-SMGCS is available however traffic situation at Bremen does not require measures to enhance capacity.
REQ-06.08.05-OSED-GBAS.0140	The Tower Runway Controller shall be able to provide a late landing clearance as late as 1NM before touchdown to air crew performing a GBAS approach in LVP.	Yes	
REQ-06.08.05-OSED-GBAS.0150	The final approach controller and Tower Runway Controller shall be able to reduce final approach spacing before GBAS equipped arrival aircraft (as compared with today ILS) under low visibility operations.	No	Currently no tools are available to identify GBAS capable aircraft (APP controller) or aircraft cleared for a GLS approach (TWR controller) in Bremen. In addition, it is difficult to the controllers to handle mixed traffic (ILS/GLS) and consider protection areas dependently.
REQ-06.08.05-OSED-GBAS.0160	ATC shall be provided the GBAS station status indication (red/green).	Yes	
REQ-06.08.05-OSED-GBAS.0170	The air traffic controller shall be displayed information on GBAS aircraft capabilities.	No	Not implemented yet.
REQ-06.08.05-OSED-GBAS.0180	ATC shall be able to differentiate between ILS and GBAS capable aircraft when both landing aids are used for approach and landing.	No	Not implemented yet.
REQ-06.08.05-OSED-GBAS.0190	ATC shall be able to manage the landings of aircraft when both ILS and GBAS are used in LVP.	Yes	
REQ-06.08.05-OSED-GBAS.0200	ATC shall be able to provide service degradation/failure information in a timely and safe manner to aircrafts when both ILS and GBAS are used in LVP.	Partly	Information is provided, however timing requirement of 1.5 seconds is not met, however is mitigated through airborne (CAT I system supports 3s).

REQ-06.08.05-OSED-GBAS.0210	ATC shall ensure no infringement of ILS CSA and OFZ during mixed ILS/GBAS landings through correct application of the landing clearance line and CAT III holding points for aircraft vacating the runway	n/a	Not implemented yet.
REQ-06.08.05-OSED-GBAS.0220	ATC shall be able to manage GBAS station failures that affect multiple runway ends when only GBAS is used.	n/a	At Bremen other approach navaids besides GBAS are available.
REQ-06.08.05-OSED-GBAS.0230	ATC shall be able to manage GBAS service degradation when only GBAS is used and when both ILS and GBAS are used for approach and landings.	Yes	
REQ-06.08.05-OSED-GBAS.0240	The phraseology used for GBAS approaches shall be determined in such a way that it prevents being confused with ILS.	Yes	
REQ-06.08.05-OSED-GBAS.0250	The air traffic controllers shall receive a training on optimised low visibility operations using GBAS.	Yes	Training defined in CONOPS
REQ-06.08.05-OSED-GBAS.0260	The phraseology to be associated with GBAS operations shall be coordinated at global level, through ICAO.	Yes	
REQ-06.08.05-OSED-GBAS.0270	The GBAS ground station information shall be promulgated in AIP.	Yes	
REQ-06.08.05-OSED-GBAS.0280	ANSP shall distribute NOTAM in case of unavailability of the GBAS/GLS service.	Yes	

REQ-06.08.05-OSED-GBAS.0290	ATC shall broadcast ATIS information regarding available GBAS/GLS approaches in LVP.	Yes	
REQ-06.08.05-OSED-GBAS.0300	The aircraft operator shall provide information on GBAS aircraft capabilities in the flight plan item 10.a	Yes	
REQ-06.08.05-OSED-GBAS.0310	A-SMGCS shall be implemented for optimised low visibility operations using GBAS.	Yes	

Table 4: Compliance Matrix to SESAR Solution #55

By **integrating the GAST C GBAS ground station with an SBAS receiver** (EGNOS capable receiver in Europe), GBAS can take advantage of SBAS's independent anomalous ionosphere monitoring. SBAS's network of dual frequency ground receivers is capable of producing a model of the ionosphere of the region which a single GBAS ground system is unable to do. GBAS brings on the other hand an improved performance (accuracy) due to local augmentation and improved Time-to-Alert (TTA). This makes the two systems complementary. The GBAS system will monitor the level of ionospheric activity in the region thanks to the SBAS receiver, and when the ionospheric activity is low, the system does not need to be so conservative. This enables the GBAS to lower the protection levels and take advantage of big VPL (vertical protection level) performance improvements (e.g. ~ **2x performance improvement** in Houston). This enables the station to serve CAT II operations with CAT I equipment. In case of increased ionospheric activity, the station reverts to its CAT I capability. The required integrity is attained at all times.

This unique adaptation, taking advantages of both GBAS and SBAS, improves operational availability while better protecting the aircraft against ionospheric event and enables CAT II operations against a GAST C (CAT I) ground station with CAT I airborne equipment.

GBAS GAST-D Concept vs GAST-C

GBAS Approach Service Types (GAST) is defined as the matched set of airborne and ground performance and functional requirements that are intended to be used to provide approach guidance with quantifiable performance. GAST-D has been introduced to support landing operations in lower than CAT I weather conditions including Category III operations.

With GAST-D concept, the ground station protects the aircraft in the range domain by monitoring each GPS measurement received on L1 frequency only against an acceptable error limit. It then transfers parameters through the VHF Data Broadcast (VDB) in order that the aircraft compute protection level to protect the aircraft in the position domain. The aircraft receives the integrity alerts regarding exceeded protection levels, but the airborne receiver has now the responsibility to select a satellite geometry subset that is adapted to its performance – this is called geometry screening. The geometry screening is the process of satellite selection according to pre-defined criteria linked to aircraft capabilities.

The aerodrome infrastructure and basic air traffic service provision requirements are unchanged compared to the baseline situation if GAST-D concept is used like ILS CAT III. However, some operational aspects associated to the GBAS CAT III operation will be impacted (e.g. procedure design and publication, maintenance, controller, and flight crew procedures). Operational methods for GLS CAT II including mentioned aspects are provided in Demonstration Report Chapter 3.4.2.1.