

Critical and Sensitive Areas of ILS and their 3rd Dimension - Examples, Effects and Proposals

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ABSTRACT

Critical and sensitive areas (CASA) have been implemented to protect ILS operation from impermanent objects on airports. The purpose is to safeguard the radiated ILS signal for the landing aircraft to be within ICAO specifications defined in ICAO Annex 10 [1]. Qualitative definitions and some numerical examples for the CASA are given in Attachment C of Annex 10. Typically the CASA are defined in the area of the radiating ILS antennas and extending around the runway (RWY) depending on the operational category. The differences between critical and sensitive areas are almost semantic; some states do not use 2 different areas. The CASA are treated as areas on the ground in 2D without any extension in the 3rd height dimension.

It is well known that the ILS guidance signal can be distorted by another aircraft starting from the same RWY. The authors have reported a case in IFIS 2012 which led almost to a fatal accident. Some states are now examining past incidents as potential CASA events. Recent operational scenarios include:

- closely-spaced parallel RWYs (e.g., 200m and 300m) where one RWY is used for landing and the other is used for starting (mixed-mode operations)
- parallel RWYs and taxiways at a larger separation of >500m

where the starting A/C has taken off but is still in the strong radiation field of the ILS Localizer. In this case, the desired/undesired signal ratio is changing negatively, because the LOC field is increasing for the starting A/C while the field for the landing A/C decreases. Another example has the approaching aircraft still high in the air, but its ILS signal has been distorted by a starting A/C, and the approaching A/C did not successfully capture the ILS LOC and deviated from the extended centerline.

Modeling and systematic simulation results for these 3 scenarios for Localizers will be presented and the physical background will be explained. The implications will be outlined, and recommendations offered. These mainly comprise information, awareness, and training for the pilots and controllers and also for the instrument procedures design task.

INTRODUCTION

Numerous papers have been published discussing purpose, dimensions, and operational issues of ILS CASA's (examples: [2], [3], [4], [5]). However, many of the papers as well as service providers' implementations and operational approaches treat the CASA's as 2-dimensional areas on the ground. This paper was precipitated by a serious operational incident on a large international airport and several more recent ones, and focuses on the 3rd dimension for Localizer (LLZ) cases.

The International Civil Aviation Organization's Annex 10, Volume 1 [1], addresses ILS multipath interference in Attachment C, paragraph 2.1.9. The following definitions are provided, in which the [highlighted] language is two-dimensional:

Definitions

- a) the ILS critical **area** is an **area** of defined dimensions about the localizer and glide path antennas where vehicles, including aircraft, are excluded during all ILS operations. The critical area is protected because the presence of vehicles and/or aircraft **inside** its boundaries will cause unacceptable disturbance to the ILS signal-in-space;
- b) the ILS sensitive **area** is an **area** extending **beyond** the critical area where the parking and/or movement of vehicles, including aircraft, is controlled to prevent the possibility of unacceptable interference to the ILS signal during ILS operations. The sensitive area is protected against interference caused by large moving objects **outside** the critical area but still normally **within the airfield boundary**.

Paragraphs 2.1.9.2, 2.1.9.3: To protect the critical area, it is necessary to normally prohibit all entry of vehicles and the taxiing or parking of aircraft **within** this area during all ILS operations. . . . This will include aircraft **on** the runway and **on** some taxiways.

Some states use ICAO-provided fixed CASA dimensions based on common aircraft sizes and the category of operation, while others define CASA areas uniquely according to airport geometry, antenna system type, and specific aircraft sizes. Samples provided in Annex 10's Figures C3A and C4B are excerpted in Figures 1 and 2.

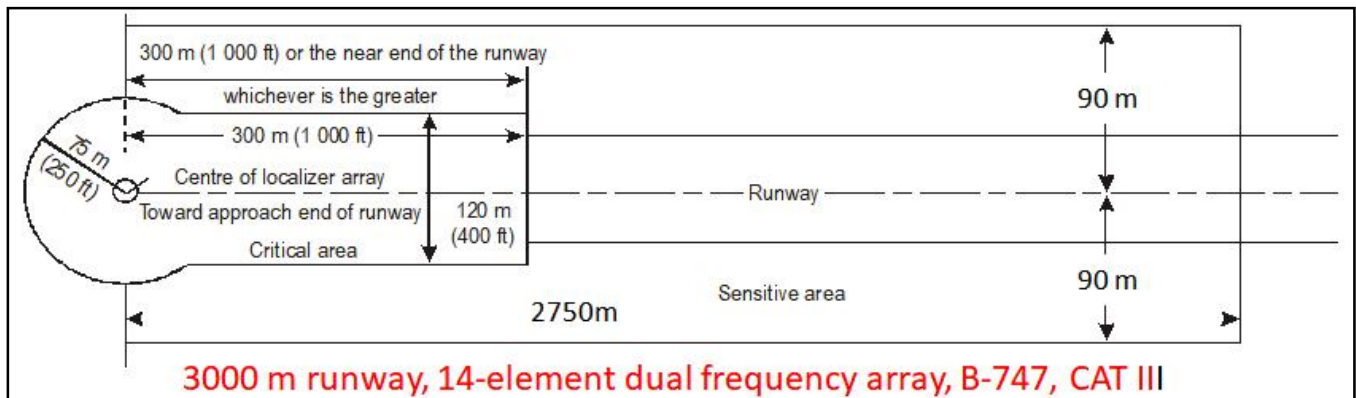


Figure 1. Sample LOC CASA Sizes

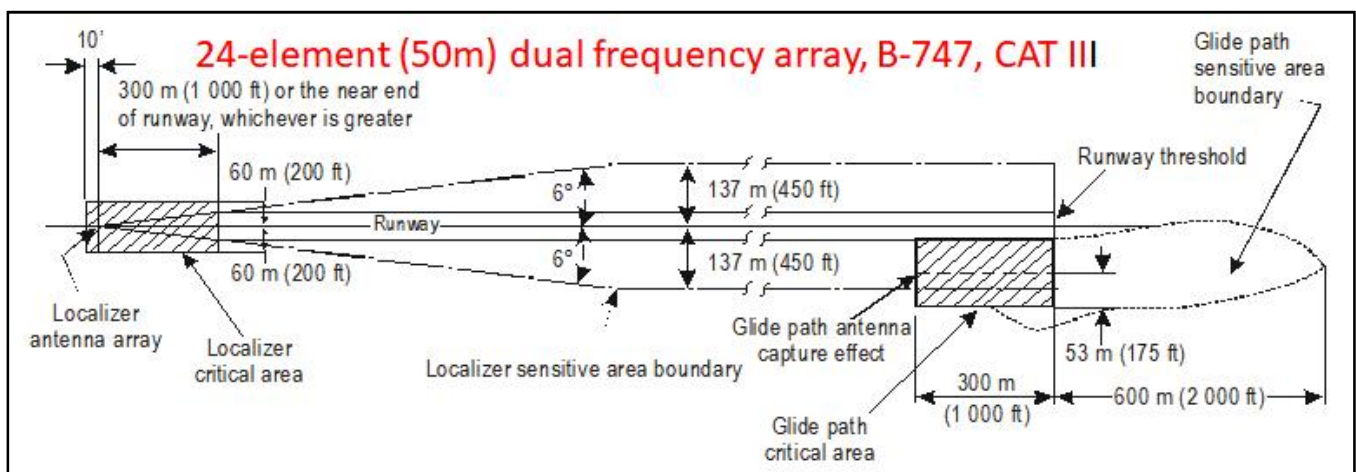


Figure 2. Sample LOC and GS CASA Sizes

In the U.S., CASA sizes are defined in Order 6750.16, *Siting Criteria for Instrument Landing Systems* [6], and their operational usage is defined in Order JO 7110.65W, *Air Traffic Control* [7], as illustrated in Figure 3. While this guidance addresses the

CASA as a 3-dimensional volume (highlighted phrases), it also provides two exceptions to protecting the CASA. These exceptions allow preceding arriving aircraft landing on the same or another runway and preceding departing aircraft to penetrate the CASA while another landing aircraft is inside the ILS outer marker (OM) or its substitute fix, even when weather conditions are below 800' ceiling and 2 nautical miles (NM) visibility, but better than 200'/2000'.

<p>3-7-5. PRECISION APPROACH CRITICAL AREA</p>		
<p>a. ILS critical area dimensions are described in FAA Order 6750.16, Siting Criteria for Instrument Landing Systems. Aircraft and vehicle access to the ILS critical area must be controlled to ensure the integrity of ILS course signals whenever conditions are less than reported ceiling 800 feet or visibility less than 2 miles. Do not authorize vehicles/aircraft to operate <u>in or over</u> the critical area, except as specified in subparagraph a1, whenever an arriving aircraft is inside the ILS outer marker (OM) or the fix used in lieu of the OM unless the arriving aircraft has reported the runway in sight or is circling to land on another runway.</p>	<p>1. LOCALIZER CRITICAL AREA</p> <p>(a) Do not authorize vehicle or aircraft operations <u>in or over</u> the area when an arriving aircraft is inside the ILS OM or the fix used in lieu of the OM when conditions are less than reported ceiling 800 feet or visibility less than 2 miles, except:</p> <p>(1) A preceding arriving aircraft on the same or another runway that passes <u>over or through</u> the area while landing or exiting the runway.</p>	<p>(2) A preceding departing aircraft or missed approach on the same or another runway that passes <u>through or over</u> the area.</p> <p>(b) In addition to subparagraph a1(a), when conditions are less than reported ceiling 200 feet or RVR 2,000 feet, do not authorize vehicles or aircraft operations <u>in or over</u> the area when an arriving aircraft is inside the middle marker, or in the absence of a middle marker, $\frac{1}{2}$ mile final.</p>

Figure 3. U.S. Operational Implementation of CASAs

BACKGROUND

In 2011, a B-777 departed the runway at an international airport after touchdown on a CAT I ILS autoland approach (Figure 4). Despite the obvious problem, very fortunately no one was seriously injured, and the aircraft was undamaged.



Figure 4. B-777 ILS Autoland Event

The runway was operating in mixed mode (landings and takeoffs from the same runway.) When the 777 was about 2.1 NM prior to touchdown, a BAe Avro began its takeoff run. When the landing 777 crossed the runway threshold, the Avro was

climbing out and still short of the runway end (Figure 5). Due to an unusually large LLZ antenna system setback, the Avro overflew the localizer antenna at a height of 740 feet 26 seconds after the 777 crossed the threshold.

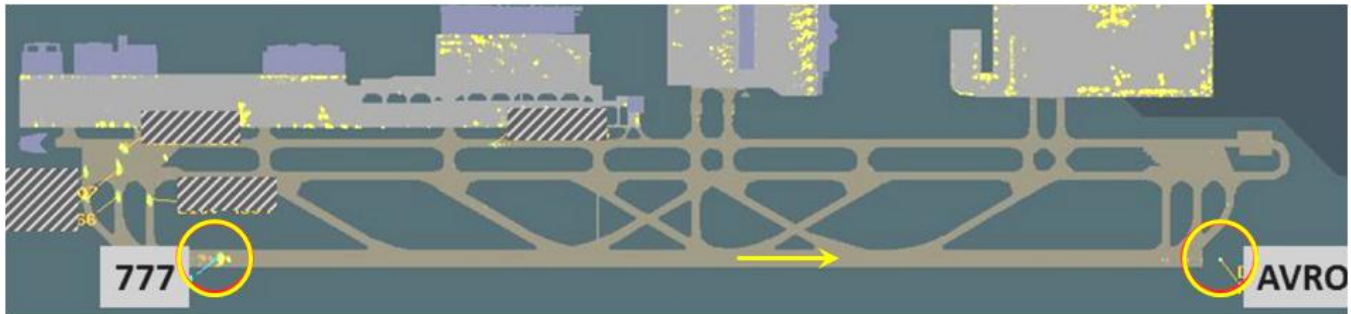


Figure 5. Relative Positions of Landing (left) and Departing (right) Aircraft

At approximately 30 feet AGL, the 777 began to roll left, and the left main gear touched down about 490 meters inside the threshold. The autopilot switched to roll out mode, and the aircraft rolled towards the left edge of the runway, crossing it at about 1100 meters down the runway. Rudder inputs disengaged the autopilot. The 777 crossed the runway to the right and exited the right edge approximately 1620 meters down the runway. The aircraft came to a stop south of the runway on grass about 60 meters off the runway and 1780 meters inside the runway threshold.

The subsequent investigation found flight data recorder data indicating the three ILS receivers recorded localizer signal deviations in both directions before the autopilot changed into roll out mode. A few seconds prior to the roll out mode change, the deviation increased to the right of the extended center line, causing the initial roll to the left to minimize the localizer deviation. Quantitative numerical simulation results can be found in the 2012 IFIS paper [4] of the authors.

DISCUSSION

Case 1. Mixed Mode and Autoland.

Starting aircraft have the potential to distort the ILS-signal for the next landing aircraft during mixed mode operation. In the ideal case, the starting aircraft climbs while remaining directly above the runway centerline, and no DDM-distortions occur for the landing aircraft due to the symmetry of the geometry. Even in an extreme case of approach lights immediately in front of an LLZ (Figure 6), the horizontal light bars and embedded wiring do not cause LLZ performance problems if they are located symmetrically around the extended centerline.



Figure 6. Example of CAT III LLZ with (Symmetrical) Approach Light Stations immediately in front of Antennas

However, if the starting aircraft deviates from the ideal climbing path/slope, asymmetric scattering components generate large distortions until shortly after the localizer is crossed. The problem is aggravated by the relative heights of the two aircraft, due to the typical vertical antenna pattern of an LLZ (Figure 7), which is horizontally polarized. The arriving aircraft is at a low elevation angle and low signal level, while the departing aircraft is at a much higher elevation angle and likely to be illuminated by much higher signal levels.

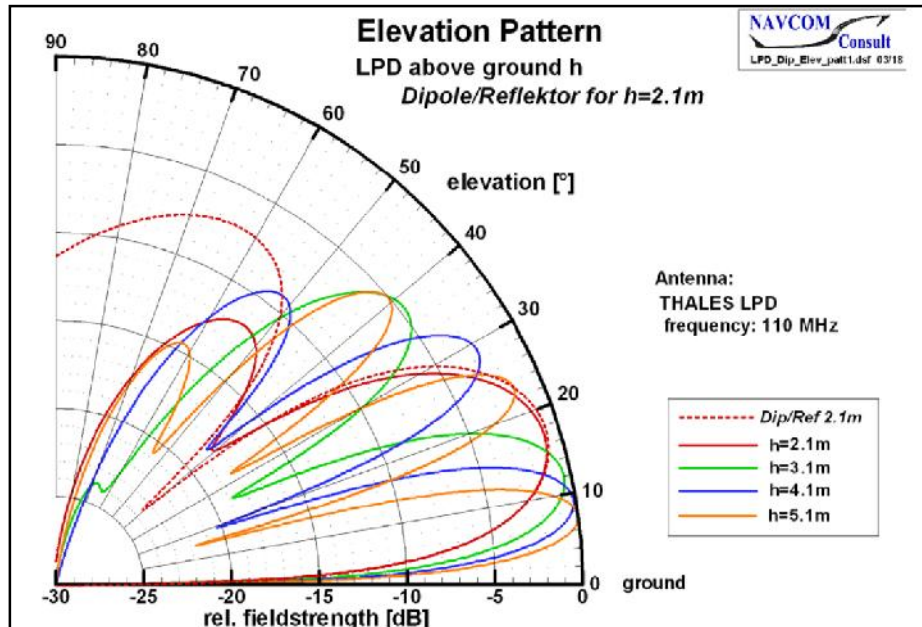


Figure 7. Elevation Pattern of LLZ Antennas: Dipole with Reflector (2.1 m) and LPD at Various Heights above Ground

To gain an awareness for the magnitude of the total system problem, a high-fidelity modeling scenario (IHSS, by NAVCOM, using Method of Moments and Improved Physical Optics) considers several parameters, including the effective separation between the arriving and starting aircraft, the splay or drift rate of the starting aircraft away from extended centerline, the starting aircraft type and climb rate, and the LLZ antenna setback, height, and type (Figure 8).

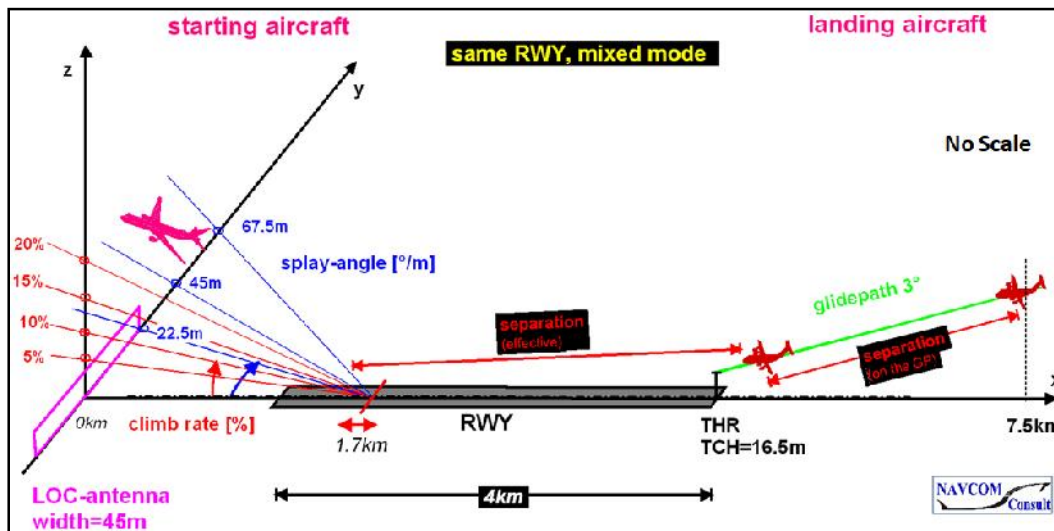


Figure 8. Modeling Scenario for LLZ Effects Resulting from Mixed-Mode Runway Use

The following figures present LLZ errors as a percentage of CAT III tolerances, for varying conditions. All scenarios assume a B-737-800 or a B-777-300 for the starting aircraft at 2700 m from the LLZ on a 4000 m runway. The vertical axis of each

graphic is the distance of the departing plane from the LLZ (0m at top, 1700 m at bottom), and the horizontal axis is the distance of the landing aircraft prior to the approach threshold while on the 3.00° glide path (0 km at left, 7.5 km at right). The LLZ antenna system is a 21/7-element array located 700 m beyond the runway stop end. Error amplitudes are presented by color, with the lightest colors being very small errors and darker colors being very large errors - black represents 100% of tolerance or more. The results assume a perfect LLZ beam except for the effects of the departing aircraft - actual installations will of course have other errors on the LLZ from static or moving objects on the airfield.

Figure 9 presents error results for departing aircraft climb rates of 5, 10, 15, and 20% (left to right), with the aircraft overhead the LLZ antenna at 22.5 m laterally from extended centerline. The antennas are mounted a nominal 2.1 m above ground. For most cases with the departing aircraft being up to 1000 m inside the LLZ, the errors are generally over 100% of CAT III tolerance throughout most of the approach.

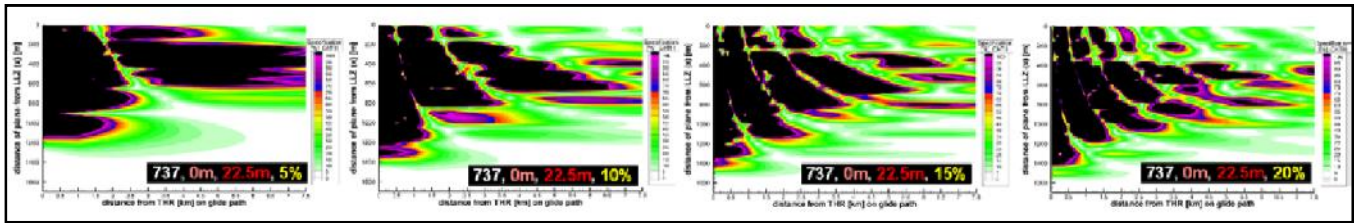


Figure 9. LLZ Errors from Departing Aircraft with 5% (left) to 20% (right) Climb Rates for 2.1 m LLZ Antenna Height

Figure 10 maintains the same conditions as for Figure 8, except that the LLZ antennas are elevated by an additional 3 m, to a height of 5.1 m. Elevating the antennas by an approximate 150% will improve the signal strength at low elevation angles for the landing aircraft, while decreasing the reflected signal levels somewhat from the departing aircraft at some parts in the higher volume. However, while the size of each "elliptical" black area is noticeably smaller, the improvements are not dramatic, and many conditions with more than 100% of CAT III errors remain. (Elevating the antennas also has potential challenges, such as maintaining mechanical stability under wind and ice loading, and increasing static error levels for some runway geometries from structures/objects low in elevation angle, such as distant hangars or taxiing/stopped aircraft.)

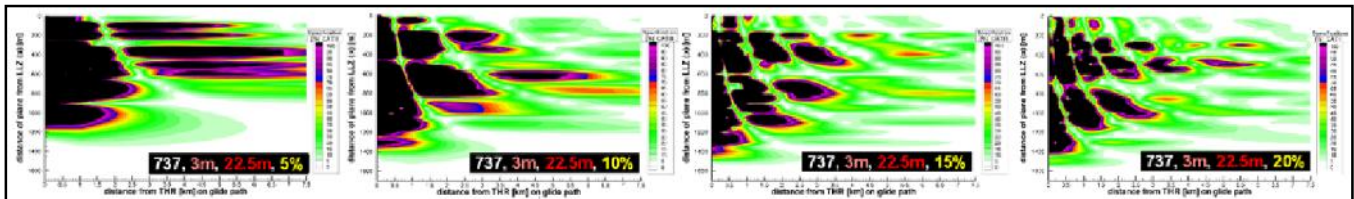


Figure 10. LLZ Errors from Departing Aircraft with 5% (left) to 20% (right) Climb Rates for 5.1 m LLZ Antenna Height

Figure 11 maintains the same conditions as for Figure 8, except that the departing aircraft's climb rate is fixed at 10%, while its splay angle (lateral drift rate) is varied such that when overhead the LLZ antennas, the aircraft offset is 22.5 m (left), 45 m (center), and 67.5 m (right) from extended runway centerline. The 22.5 m offset at left thus has the aircraft directly over one edge of the antenna system. The areas in the graphic with errors $\geq 100\%$ are somewhat larger in general than for Figure 9 conditions.

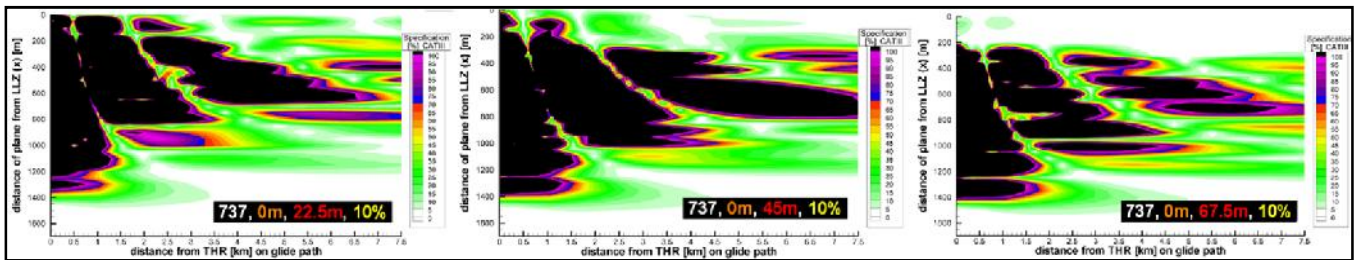


Figure 11. LLZ Errors from Departing Aircraft, Lateral Offsets over LLZ of 22.5 (left) to 67.5 m, 2.1 m LLZ Antenna Height

Finally for the mixed mode scenario, Figure 12 maintains the same conditions as Figure 11, except that the departing aircraft is changed to a larger model, a 777-300, with a 10% climb rate and lateral offsets when overhead the LLZ antenna of 22.5 m, 45 m, and 67.5 m. Not surprisingly, the graphical areas with $\geq 100\%$ errors are larger.

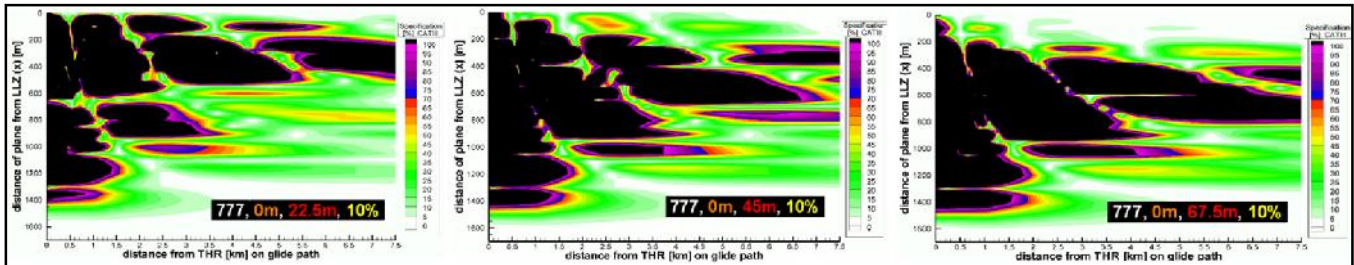


Figure 12. LLZ Errors from Departing Aircraft, Lateral Offsets over LLZ of 22.5 (left) to 67.5 m, 2.1 m LLZ Antenna Height

Case 2. Close parallel Runways for Landing and Starting Aircraft.

Another common actual airport scenario related to CASA is simultaneous takeoffs and landings from TWO runways which are typically somewhat closely spaced, e.g., 250 and 400 m, as shown in Figure 13. In the following examples, the departing aircraft is again a B-737-800 starting its takeoff roll on a parallel runway at 2700 m from the landing aircraft's LLZ. The splay angle/lateral offset of the departing aircraft from its extended runway centerline is zero degrees/meters - ie, there is no lateral drift during the departure. The runway separations, departing aircraft climb rate, and antenna mounting height for the landing aircraft's LLZ will be varied. The resulting guidance errors are calculated for the landing aircraft's receiving antenna at a height of 4 m.

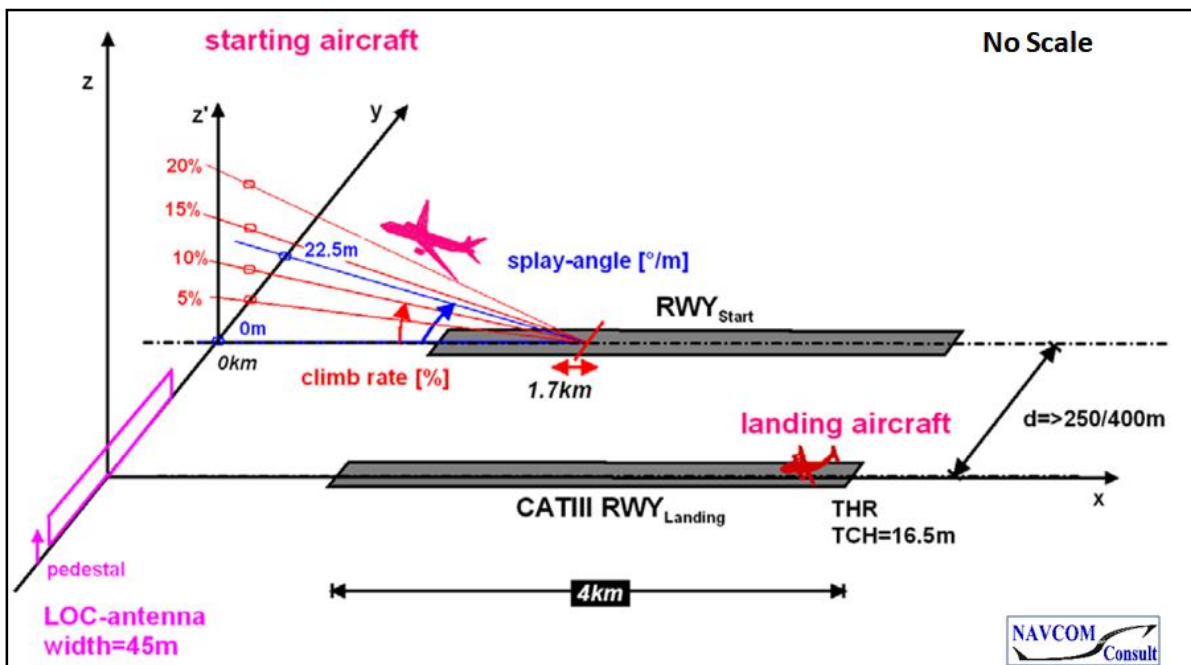


Figure 13. Two-Runway Scenario, Simultaneous Takeoffs and Landings

For each two-runway scenario, the predicted error levels from the departing aircraft in the following graphics are presented as a percentage of CAT III tolerances. Error amplitudes are presented by color, with the lightest colors being very small errors and darker colors being very large errors - black represents 100% of tolerance or more. The vertical axis presents the distance in meters (2700 to 1000) of the departing aircraft to a point abeam the LLZ antennas - a distance of 1000 m represents the stop end of the departure runway. A second vertical axis if present shows the time in seconds (~ 0 to 24) from the start of the departing aircraft. The horizontal axis is the distance of the landing aircraft from its LLZ antenna (~ 0.5

km left to 4.5 km right). The results assume a perfect LLZ beam except for the effects of the departing aircraft - actual installations will of course have other errors on the LLZ from static or moving objects on the airfield.

Figure 14 presents the predicted landing aircraft guidance errors for the scenario of a 15% climb rate for the departing aircraft, 250 m runway separation, and either a typical 2.1 m mounting height (left) or 5.1 m height (right) for the LLZ antennas. For the 2.1 m LLZ antenna height case, the errors exceed 100% of CAT III tolerances for the departing aircraft within approximately 400m of the departure end of its runway, and the landing aircraft is within approximately 0.5 km of its approach threshold.

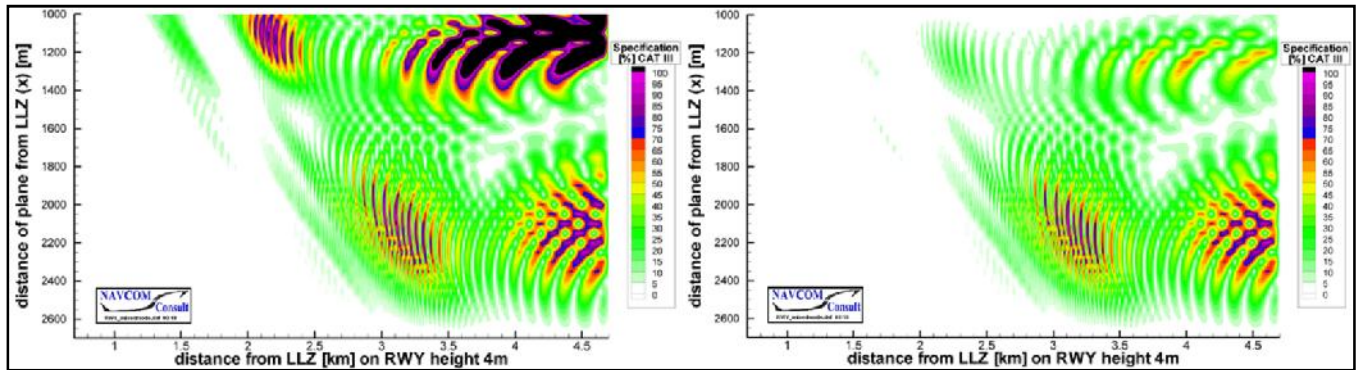


Figure 14. Errors for 250 m Runway Separation, 15% Climb Rate, LLZ Antenna Height of 2.1 m (left) and 5.1 m (right)

Figure 15 presents the errors for the same conditions as in Figure 13, except that the departing aircraft's climb rate is changed from 15% to 20%. Error magnitudes in general are similar, but their specific locations change due to the changed geometry from the faster-climbing departure aircraft.

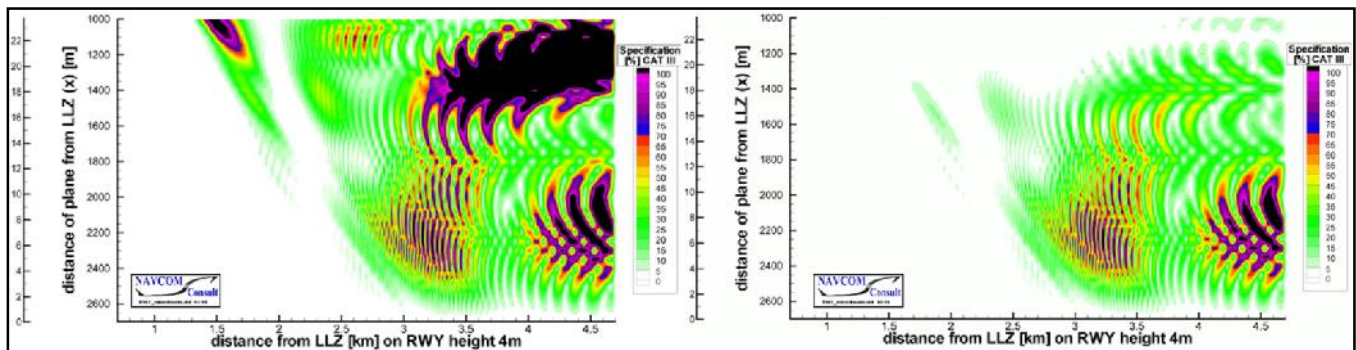


Figure 15. Errors for 250 m Runway Separation, 20% Climb Rate, LLZ Antenna Height of 2.1 m (left) and 5.1 m (right)

Figures 16 presents the errors for a climb rate of 20% and a typical 2.1 m mounting height of the LLZ antennas, for both 250 m (left) and 400 m (right) runway separation. Intuitively, the errors are reduced for the larger runway separation case.

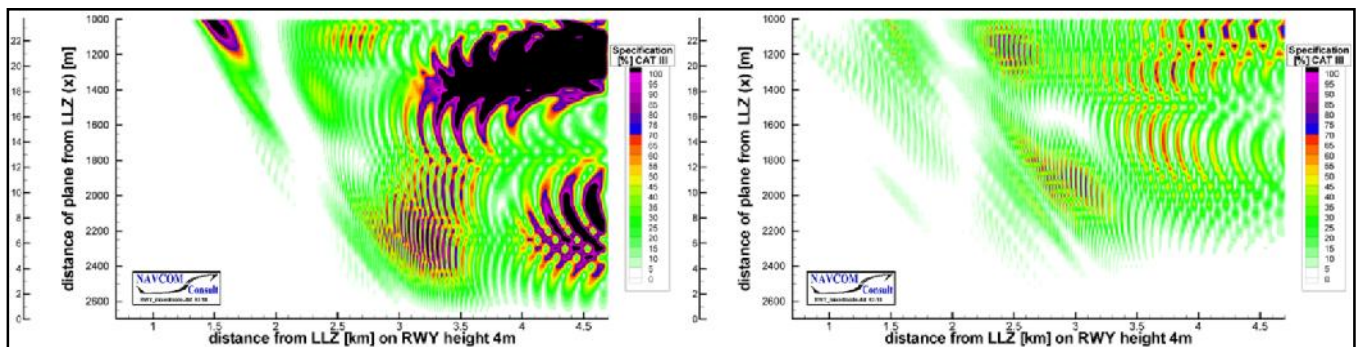


Figure 16. Errors for 250 m (left) and 400m (right) Runway Separation, 20% Climb Rate, LLZ Antenna Height of 2.1 m

Case 3. Effects on Avionics by Mixed Mode Operation.

Another example of a CASA 3rd dimension issue recently occurred at a large international airport. An arriving aircraft was executing an arc toward centerline, prior to capturing the LLZ. A departing aircraft in mixed mode runway operation introduced guidance errors similar to those in the preceding two cases, but while the arriving aircraft was still turning toward the LLZ course. The resulting oscillatory guidance signals exceeded an apparent software-based deviation rate limit in some way and caused the autopilot to change incorrectly to a Heading Hold condition. Figure 17 illustrates the nominal flight path with distances to the runway between 12 and 4 km. The dashed white line indicates the Heading Hold angle during the linear portion of the flight, prior to manual intervention by the crew.



Figure 17. Flight Path of Approaching Aircraft experiencing Heading Hold due to Departing Aircraft Overflight Effects

Figure 18 illustrates the calculated effects of the overflight on the arriving aircraft, which did not successfully capture the LLZ guidance. For both graphics, the horizontal axis is UTC time in seconds. The upper graphic illustrates the height of the departing (overflight) aircraft in feet on the vertical axis, with its decreasing distance to the LLZ in meters superimposed on the horizontal axis. When this departing aircraft was overhead the LLZ antennas, it was approximately 800' above the runway. The lower graphic illustrates the resulting guidance errors in units of microamperes (μA) of Difference in Depth of Modulation (DDM) or deviation (left vertical axis) to the arriving aircraft, which was initially in a capture mode, then subsequently in a heading-hold mode. The right vertical axis presents the arriving aircraft's lateral position in meters from runway centerline extended. For approximately the first half of the time shown, the change in DDM is a curve as the aircraft turns toward the LLZ course line. At the onset of the errors from the preceding aircraft's overflight, the lateral position of the aircraft becomes linear with time as it transitions through the linear portion of the LLZ guidance in a heading hold mode. Note that throughout this time, the arriving aircraft is in the main beam of the LLZ (i.e., within $\pm 100 \mu A$).

This behavior of a temporary heading hold while briefly encountering deviation errors due to a departing aircraft's overflight of the LLZ may be somewhat sensible only if an aircraft is fully captured on the LLZ and already flying inbound on extended centerline at the onset of the oscillatory errors. These conditions are encountered frequently at most airports. In this case, however, the heading hold condition was initiated shortly prior to the aircraft capturing the LLZ course and remained until the aircraft broke out of the overcast. Fortunately, the crew was able to visually discern in this case that the aircraft was already well left of the runway centerline. The crew manually turned the aircraft toward extended centerline for a missed approach, and a subsequent approach was conducted normally.

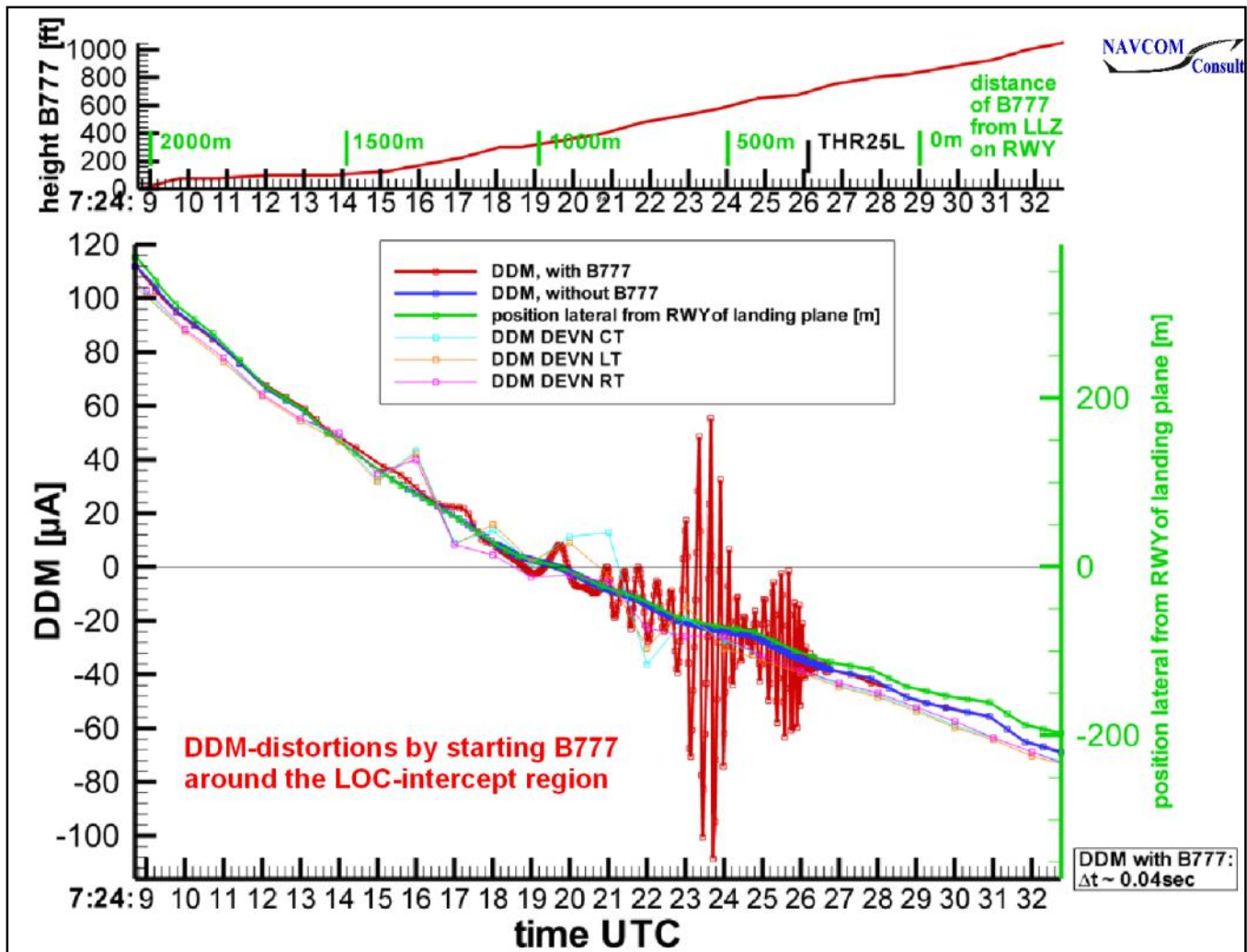


Figure 18. Calculated Double Dynamic DDM Guidance Errors from Overflight to Aircraft Attempting LLZ Capture

CONCLUSIONS

1. ILS Critical Areas and Sensitive Areas (CASA) are defined, perhaps unintentionally, in terms of 2-dimensional areas on the ground when in fact their negative effects occur in a 3-dimensional volume.
2. Although some states acknowledge the 3-dimensional nature of CASAs, their operational procedures may or do allow violation of the area or volume on a routine basis for landing and departing aircraft, at least for Category I operations.
3. A well-publicized incident in 2011, in which a landing B-777 departed the runway, was clearly due to the effects of a departing aircraft overflying the Localizer antenna system. It provided intuitive emphasis of the 3-D nature of CASAs.
4. The guidance errors to the landing aircraft in the 2011 event were enlarged in duration and magnitude by the unusually large distance of the LLZ antenna system beyond the stop end of the runway.
5. High-fidelity simulations readily duplicate the double dynamic conditions leading to the 2011 event, by considering departing aircraft type, relative positioning or effective separation between departing and landing aircraft on a mixed-mode runway, climb rate and lateral offset of the departing aircraft, and LLZ antenna system characteristics.

6. Guidance errors to an arriving aircraft in mixed-mode runway operation readily exceed 100% of CAT III tolerances for most combinations of aircraft separation and departing aircraft climb rate and lateral drift.

7. Guidance errors from a departing aircraft are larger for lower heights of the simultaneously arriving aircraft in its final approach, due to the reduced level of the horizontally polarized direct signal from the Localizer.

8. For closely-spaced parallel runways, the effects of a departing aircraft "overflying" (laterally) an LLZ supporting an arriving aircraft on a 2nd runway are reduced substantially when compared to mixed-mode single-runway operation. However, the guidance errors can still easily exceed 100% of CAT III tolerances depending on the scenario parameters.

9. An adapted or optimized separation between departing and landing can improve some aspects of the three cases presented, but cannot solve the problems of the 3D-CASA generally. (Case 1 would require a larger separation; case 2 requires a separation in a way that the next landing aircraft is still safely in the air; case 3 would require a shorter or a larger separation.)

10. Elevating the LLZ antennas provides small improvement in CASA violation effects on a mixed-mode runway but does not solve the issue generally. It can provide moderate improvement for closely-spaced parallel runway conditions, while increased runway separation (e.g., from 250 m to 400 m) provides similar magnitude improvements.

11. Aircraft not yet established on the LLZ course can be affected by guidance errors from 3-D CASA violations if their avionics algorithms, e.g., in the autopilot, do not check for appropriate conditions before changing modes.

12. A widest aperture Course array in the LLZ antenna system will not improve these pre-capture events from 3-D CASA intrusions if the distorting aircraft is fully in the Clearance region or the main beam of the Course array.

RECOMMENDATIONS

1. Modify definitions of CASAs to explicitly refer to 3-D volumes near ILS antenna systems, especially for LLZs.
2. Reconsider existing operational exemptions from protecting the CASAs by preceding landing or departing aircraft.
3. Improve pilot/controller awareness of the significant guidance errors from aircraft penetrating 3D CASA volumes.
4. Since many landings occur in good visibility but using autoland capability, Improve pilot and controller awareness and cooperation in particular for the critical autoland operation under these conditions.
5. Implement adapted or site-specific separations (e.g., for unusual LLZ setbacks) to address the three cases presented.
6. Test and improve avionics algorithms for appropriate response to the effects of 3D CASA penetrations.

ACKNOWLEDGMENTS

The numerical simulations were carried out by Mr. Biermann und Mr. Mundt of NAVCOM Consult.

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