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Definition, Testing, and Application of Instrument Landing System (ILS) Critical Areas

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Critical Areas -- Definition

- ILS Critical Areas (CA's) are areas near guidance-producing stations of the ILS that must be protected from moving or temporarily stationary objects
- Problem is multipath reflections that contaminate the quality of guidance
- Stations in question are:
  - Localizer (azimuth guidance)
  - Glide Path or Glide Slope (elevation guidance)

Critical Areas -- Application

- Critical area boundaries are identified on airports by painted markings and lighted signs
- Air Traffic Controllers and pilots refer to the boundaries as “hold lines”
- Hold Lines are defined for visual and for instrument (low visibility) conditions
- Large CA’s reduce acceptance and departure rates in low visibility weather

Motivation for Current Work

- CA's were last defined for FAA in 1989
- Since then, various changes have occurred:
  - New aircraft types (e.g., A380)
  - Additional ILS antenna system types
  - More challenging taxiway and runway geometries
- ILS Siting Handbook (Order 6750.16) defines CA sizes, and is currently in revision

Critical Area Sizes - International and U.S.

- CA guidance is provided by the International Civil Aviation Organization (ICAO) in its document "Annex 10"
- Member countries provide specific sizes and application rules
- Some significant differences exist between ICAO and US approaches to critical areas

ILS Protected Area Characteristics

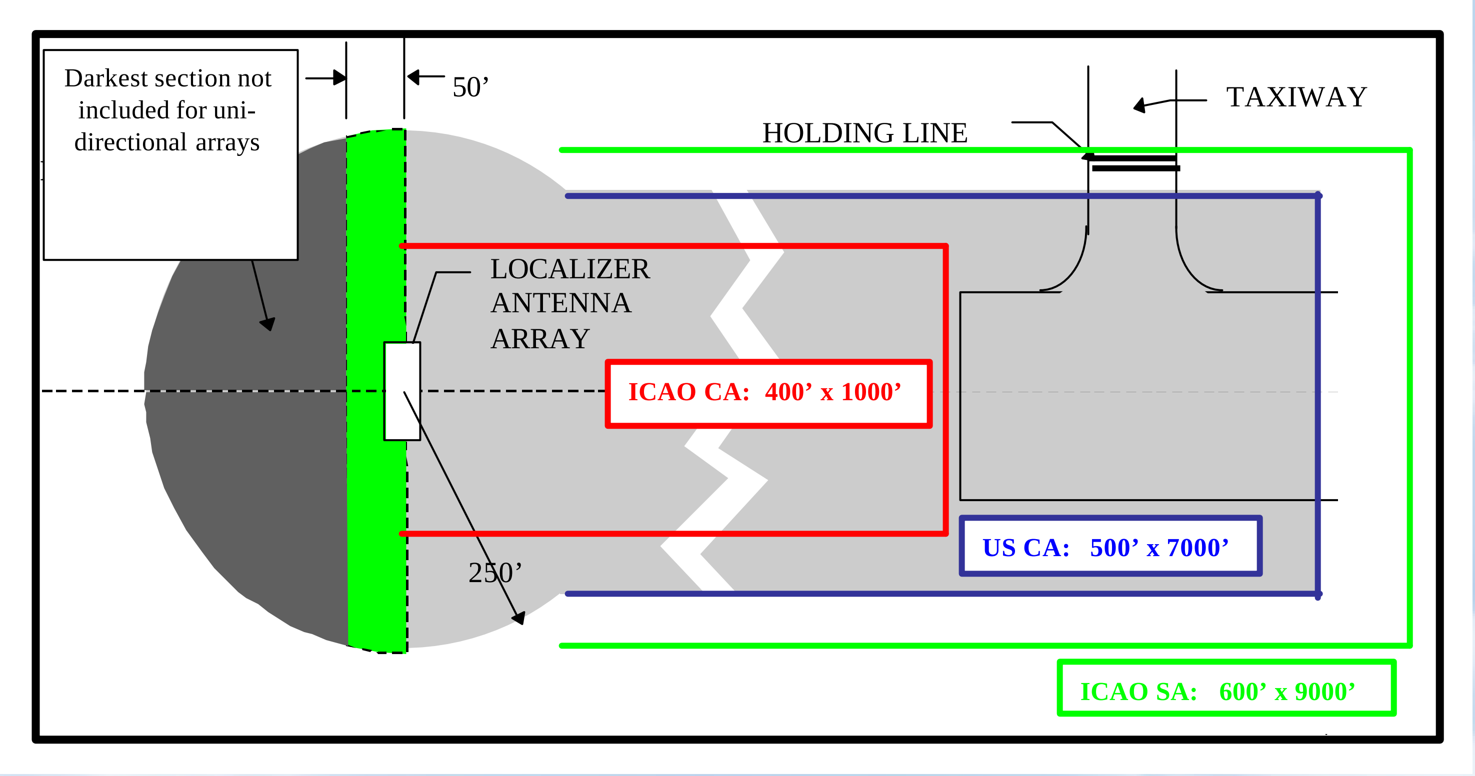
Characteristic	ICAO		U.S.	
Area & protection conditions	Critical Area	Protected during ALL (e.g., good weather) ILS Usage	Critical Area	Normally protected, with exceptions, when weather worse than 800' ceiling and/or 2 miles visibility
	Sensitive Area	Movement controlled during ILS Operations		
Hold Lines	Can vary with aircraft type		Placed for most demanding aircraft size and LOC course width	
Area sizes defined for…	Small, medium, large aircraft Category of Operation ILS Antenna system type			
Size considers static multipath?	Yes		No	

ICAO Definitions -- Critical and Sensitive Areas

- Critical Area **(CA)** -- "… an area of defined dimensions…where vehicles, including aircraft, are **excluded** during **all ILS operations**."
- Sensitive Area **(SA)** -- "… area beyond the critical area where the parking and/or movement of vehicles, including aircraft, is **controlled** to prevent the possibility of unacceptable interference…during ILS operations. The SA is protected …[from objects] … outside the CA but still normally within the airfield boundary."

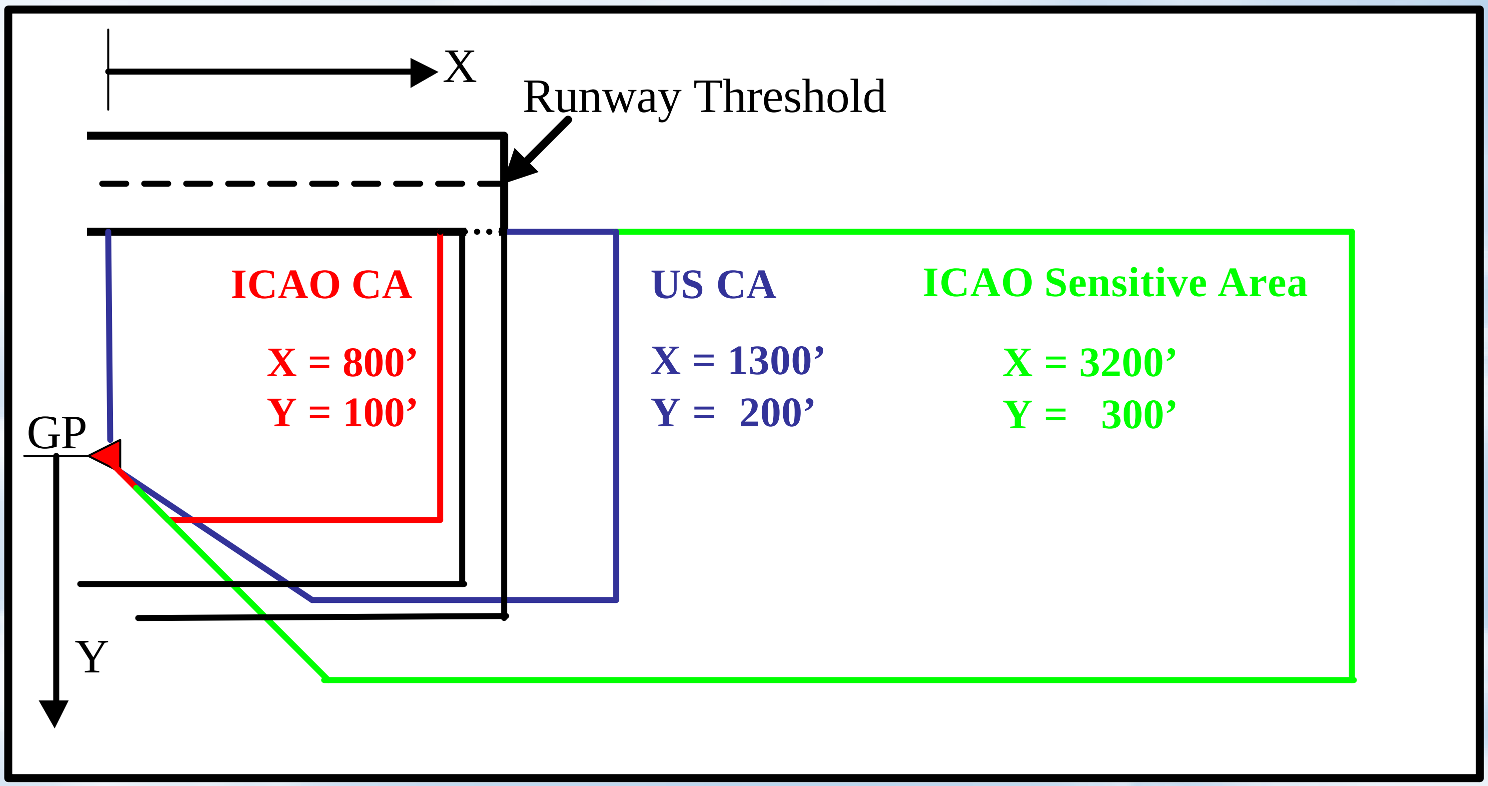
ICAO and US Localizer Critical Area Sizes

Large Aircraft (747),
Category III (lowest visibility) operation



ICAO and US Glide Path Critical Area Sizes

Large Aircraft (747),
Category III (lowest visibility) operation

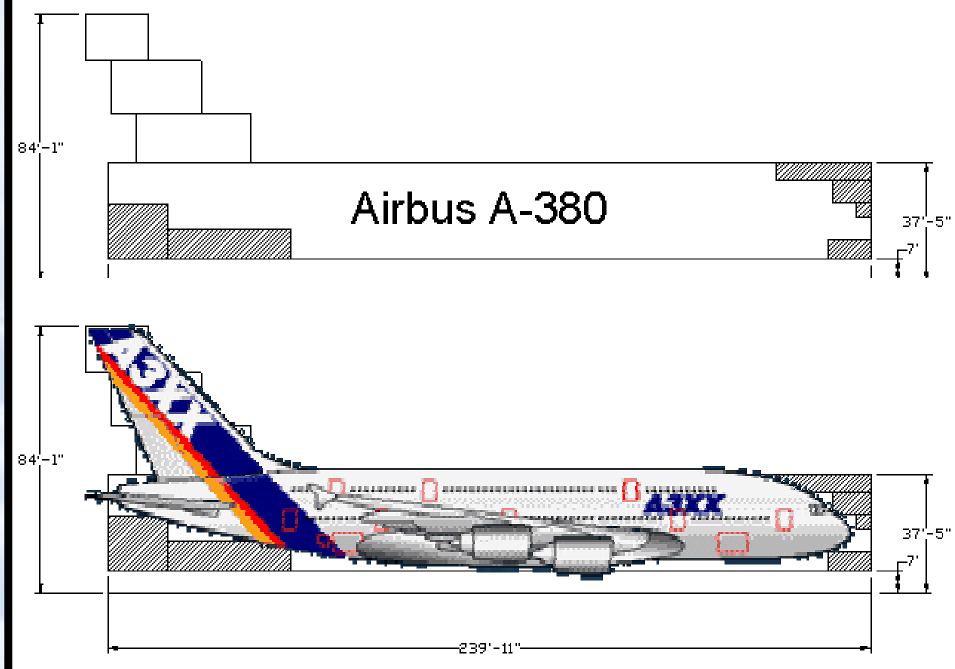


Defining Critical & Sensitive Area Sizes

- Reflections from vehicles on airports can be procedurally well controlled.
- Taxiing and temporarily parked aircraft are the dominant source of dynamic ILS guidance degradation
- Therefore, mathematical modeling of aircraft effects determines critical area boundaries.

Mathematical Model

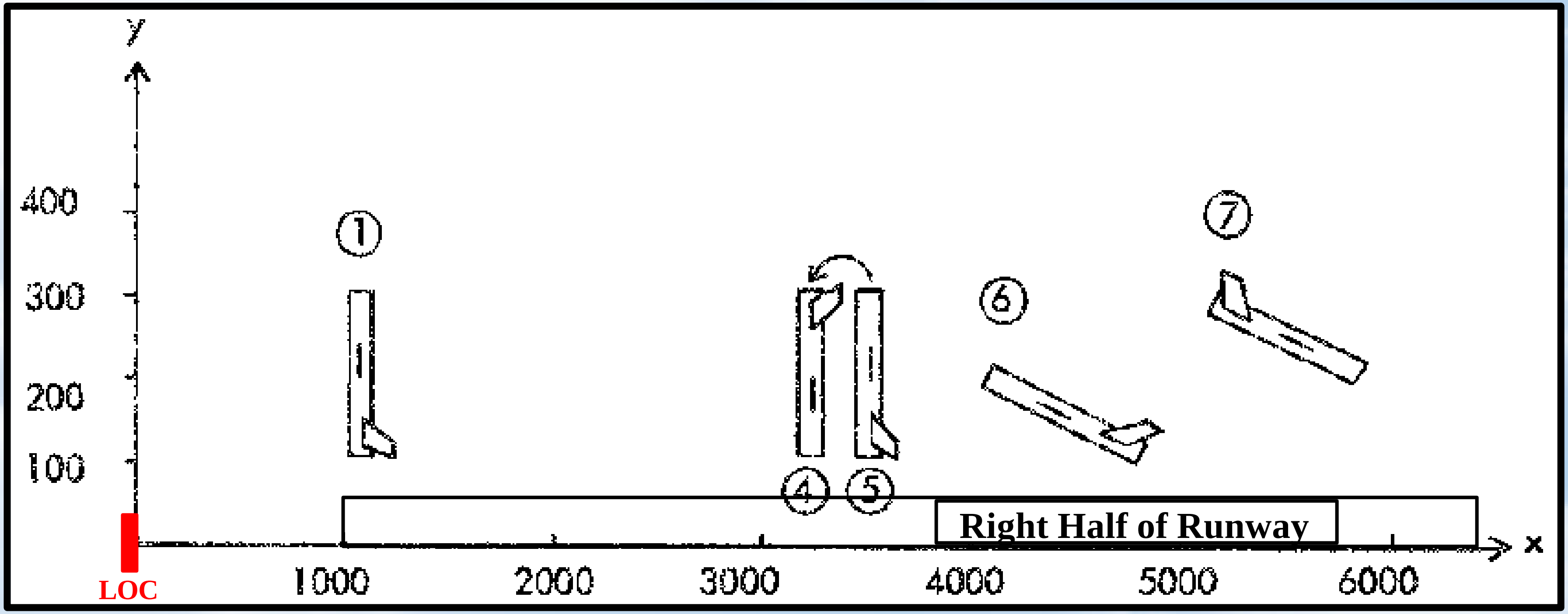
- Physical Optics model completed at Ohio University in 1978
- Aircraft simulated by appropriate combination of perfectly-reflecting flat rectangular plates
- Validated by using actual aircraft in various positions and orientations near ILS antenna systems
- Validation flight measurements conducted by OU in 1982 and ongoing



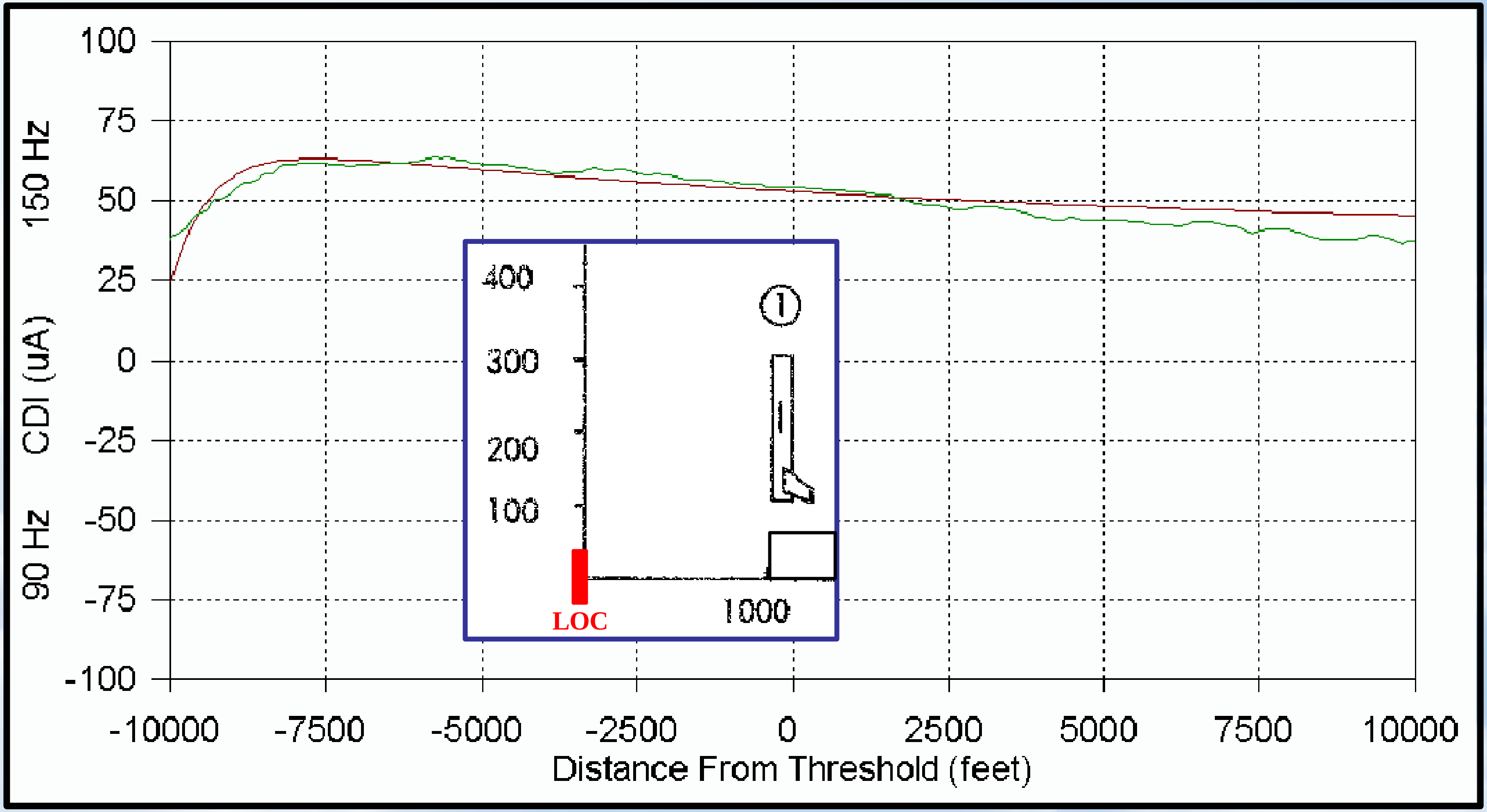
Note: Shaded plates' effect subtracted from scattered field.

Validation Parameters

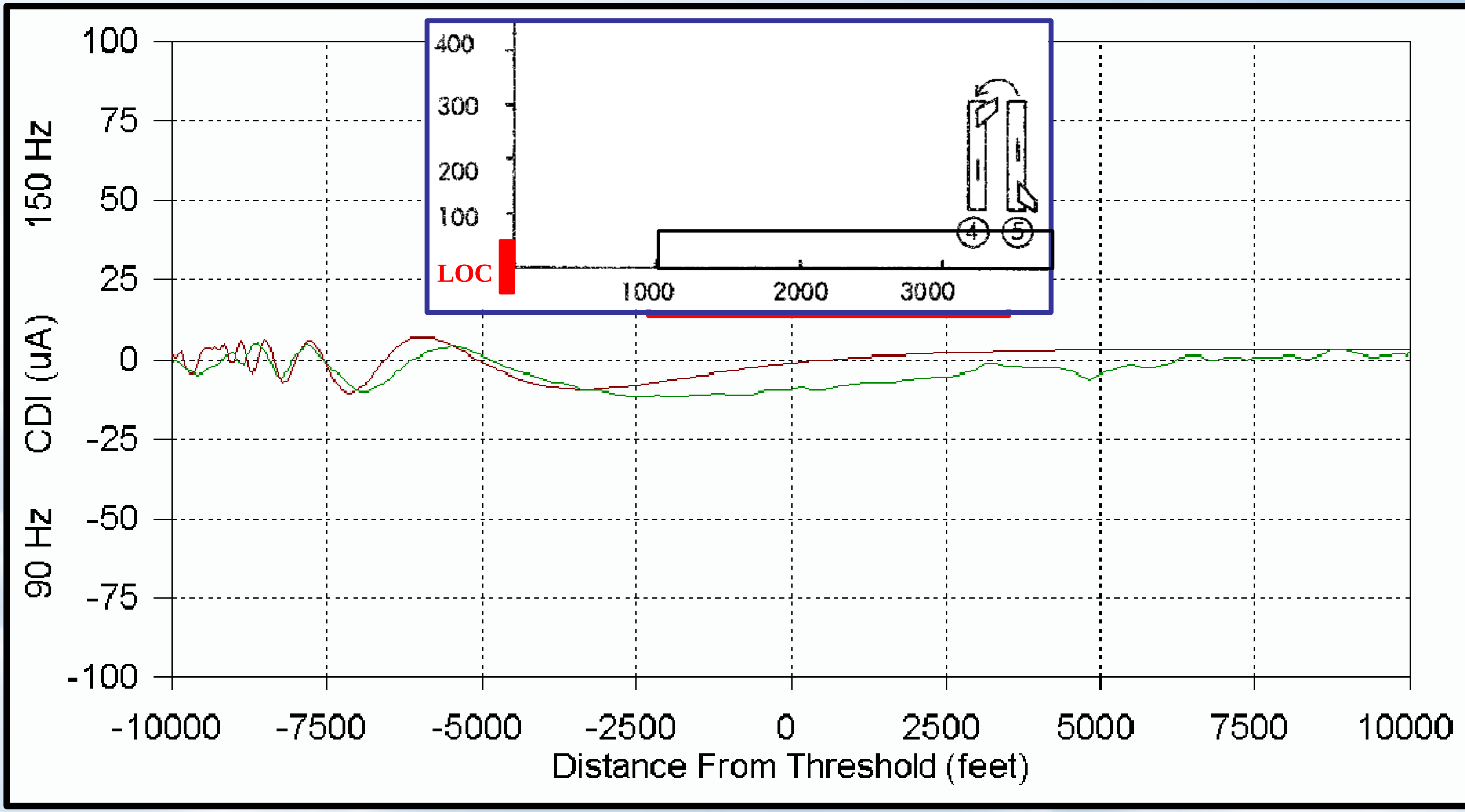
- B-747
- Dallas/Ft. Worth Runway 17L
- 2-frequency Localizer antenna, 14/6 TWA
- October, 1982



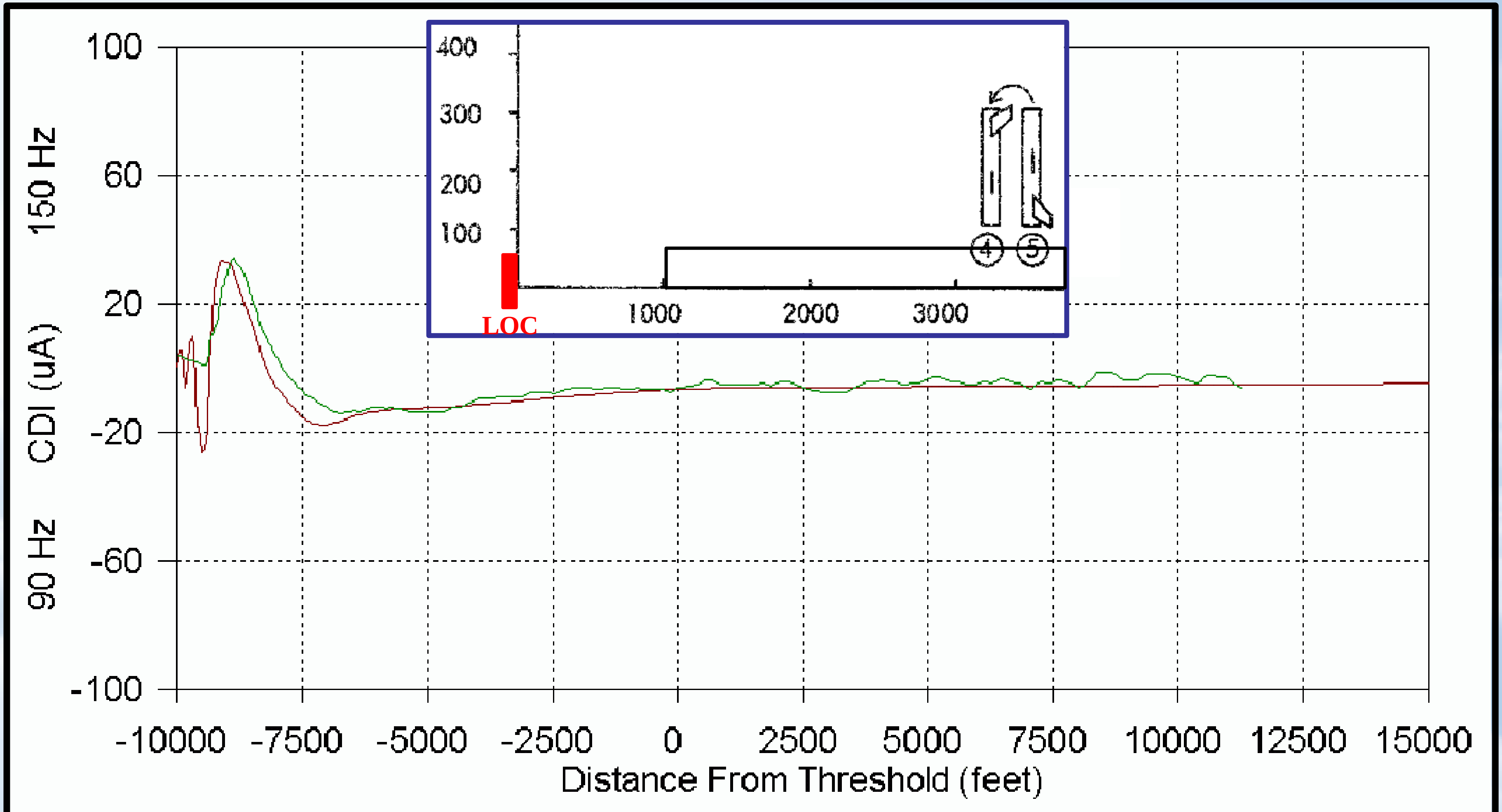
Position #1, Perpendicular, Tail Towards Centerline



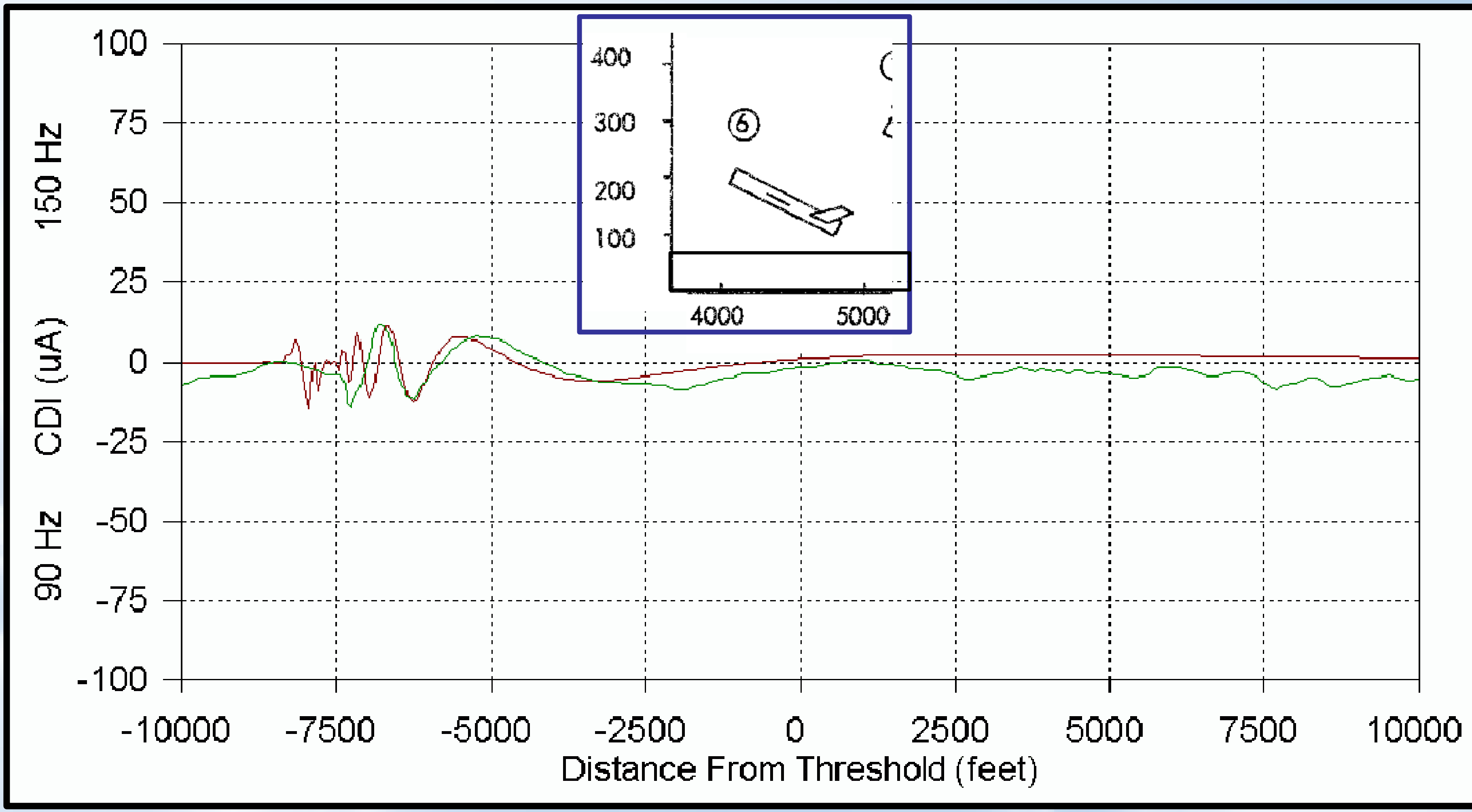
Position #4, Perpendicular, Tail Away From CL



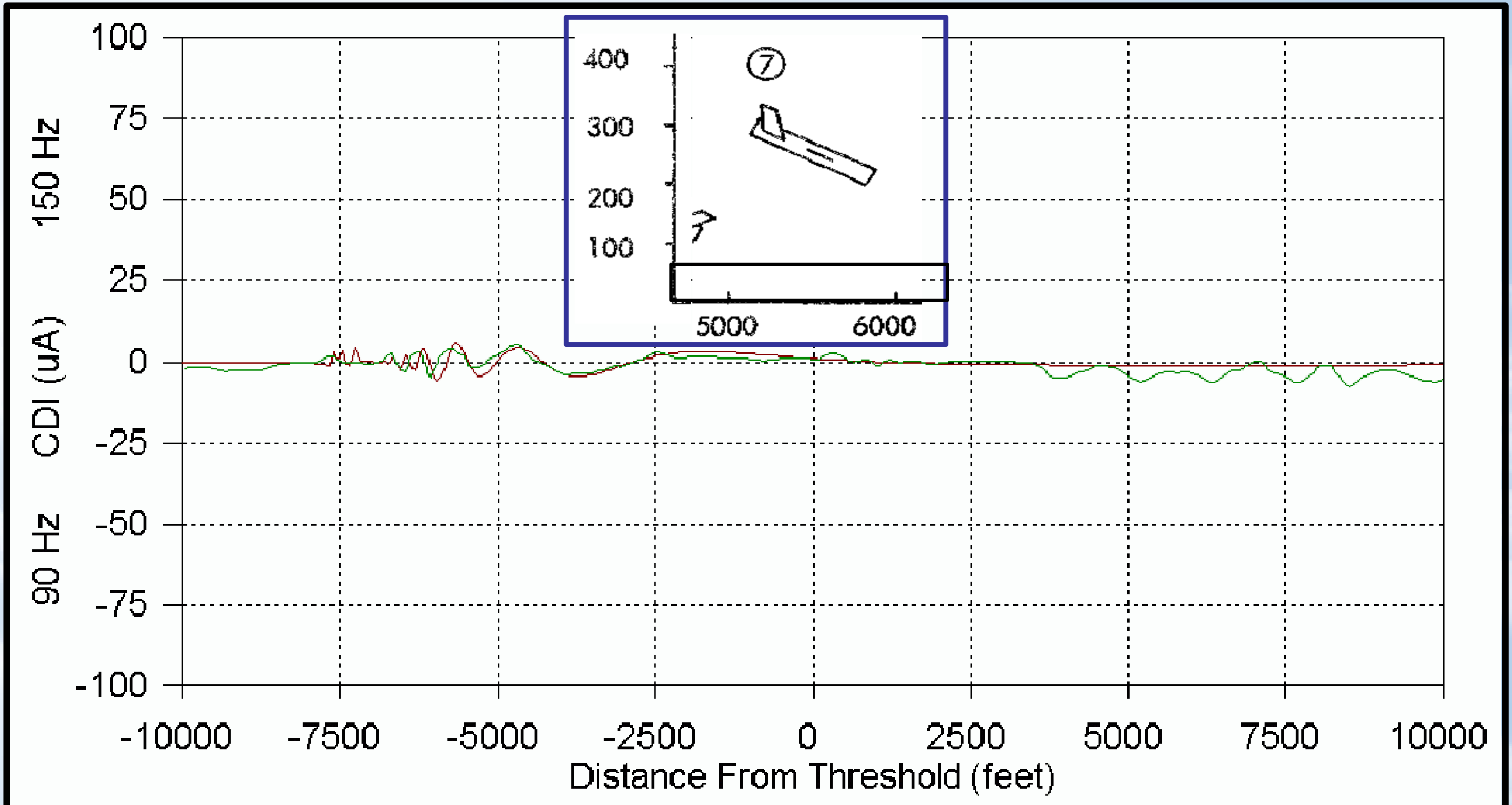
Position #5, Perpendicular, Tail Towards CL



Position #6, Tail Angled Toward Runway



Position #7, Tail Angled Away from Runway



Aircraft Sizes and Existing Classification

- Current critical areas are defined by aircraft size class
- Existing classification system has only three sizes
- Small and medium size classes have large differences in tail heights and fuselage lengths

Class	Tail Height (ft)	Conditional	Fuselage Length (ft)
Small	<20	OR*	<60
Medium	<38	OR*	<160
Large	>38	OR	>160
*Proposed to become "AND"			

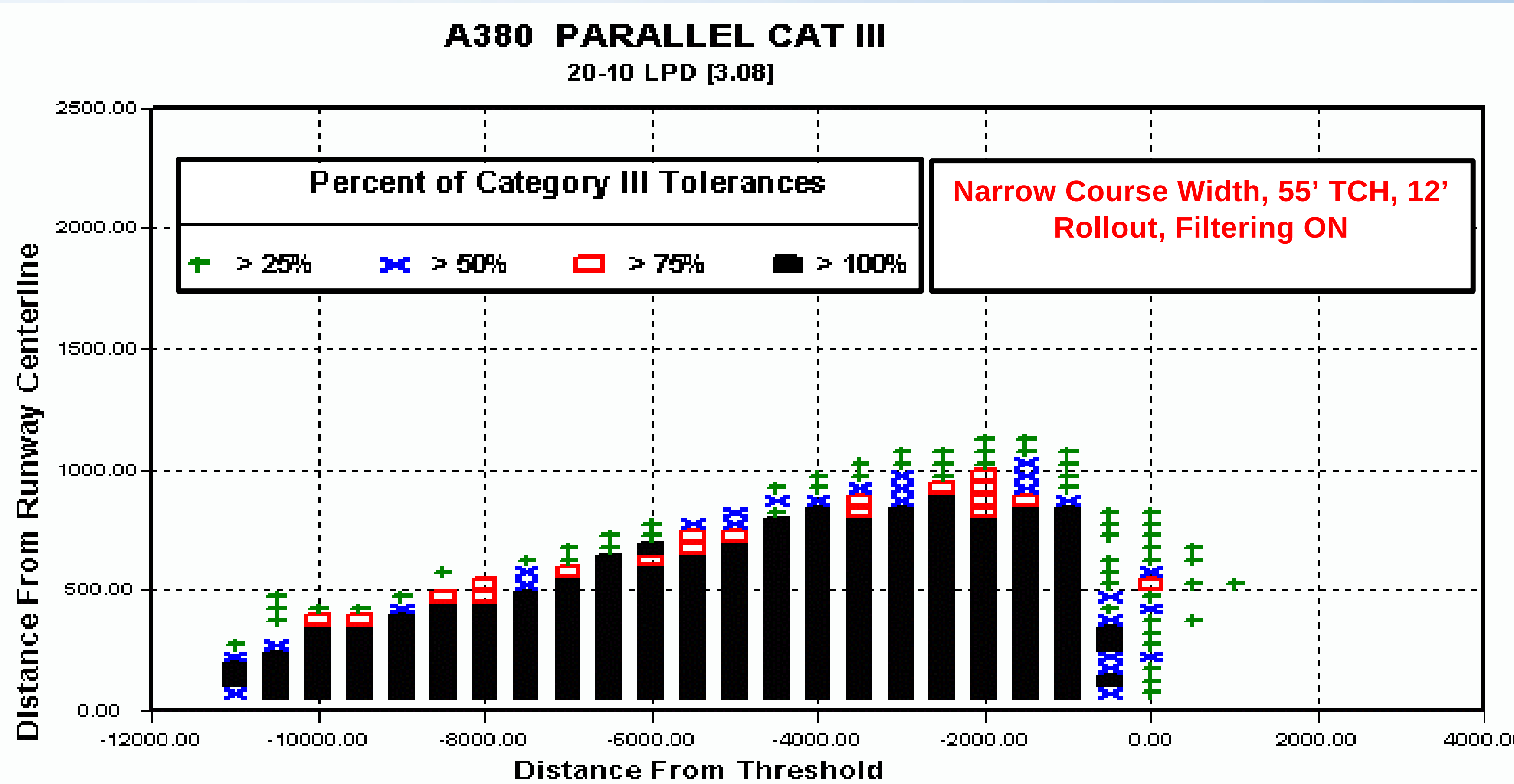
Aircraft	Tail Height (ft)	Fuselage Length (ft)	Class
B-737	36.5	109.6	Medium
B-747	63.7	231.8	Large
B-757	44.5	155.3	Large
B-767	52.0	159.2	Large
B-777	60.8	209.8	Large
A-320	38.7	123.3	Large
A-330	58.7	193.8	Large
A-380	84.0	239.9	Large

Presentation of Modeling Results

- In following graphics, errors from aircraft reflections are shown as percentage of tolerance,
  e.g. >25%, >50%, >75%, >100%.

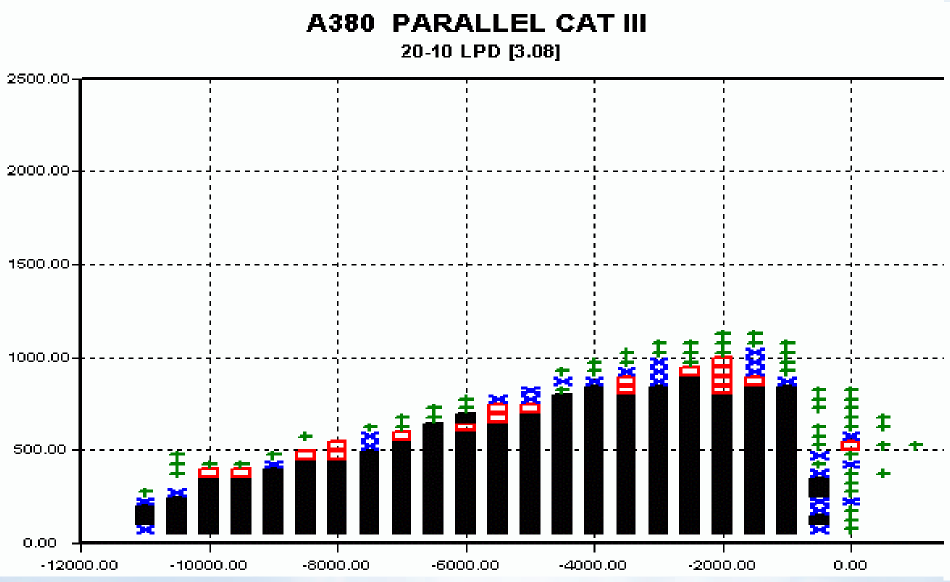
- Aircraft positions are varied with…
  – Fuselage parallel to runway, tail toward ILS facility
  – Fuselage perpendicular to runway, tail away from runway centerline
- Positions are defined by center of aircraft
- Worst-case error for each position plotted

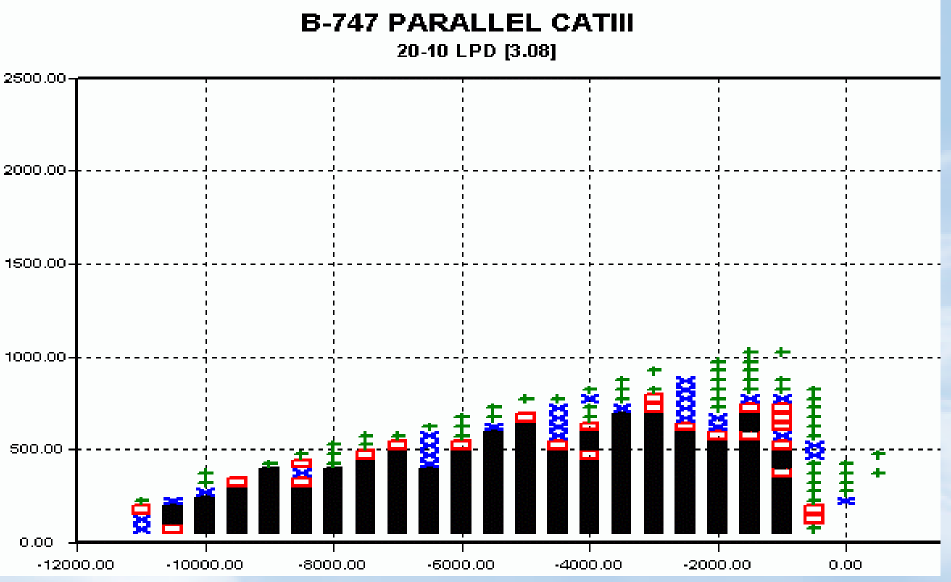
Sample Localizer Result



Comparison, A-380 & B-747, Localizer

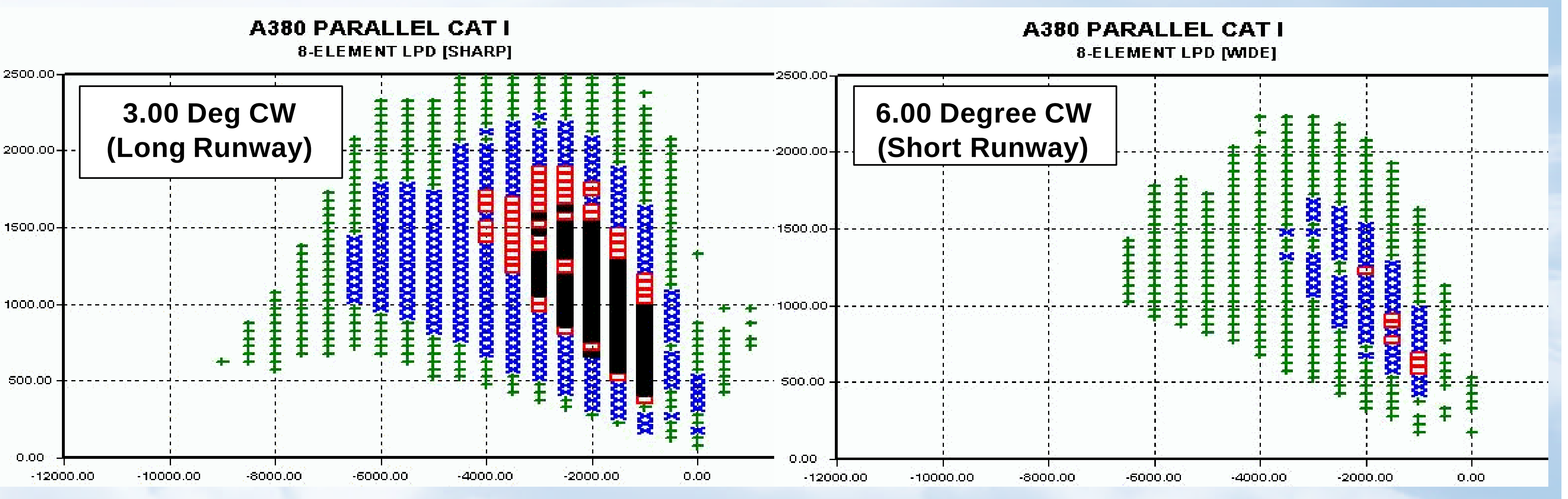
3.00 Deg Course Width (Long Runway), 55' TCH, 12' Rollout, Filtering ON



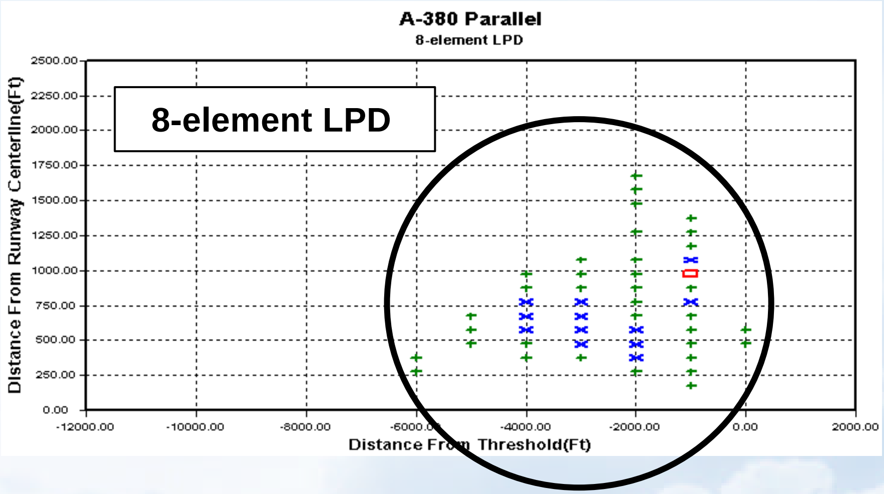


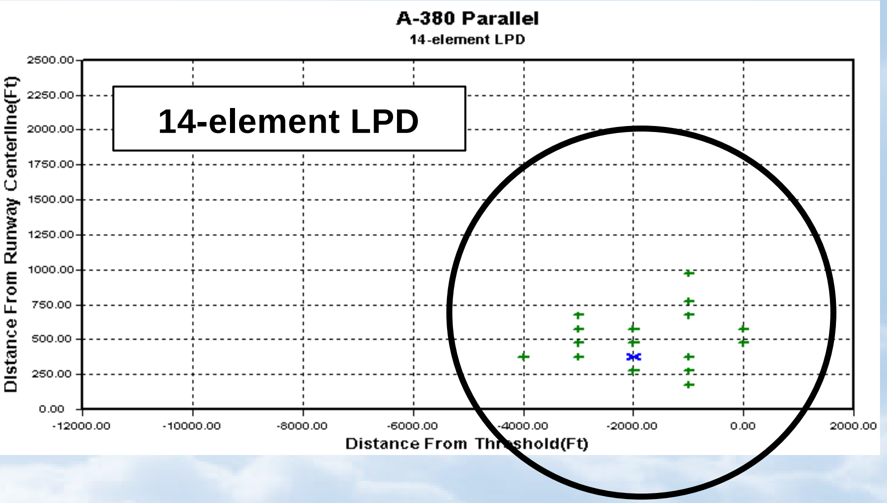
Effect of Varying Localizer Widths (CW's)

55' TCH,6' Rollout, Filtering OFF



Effect of Different Loc Antenna Systems

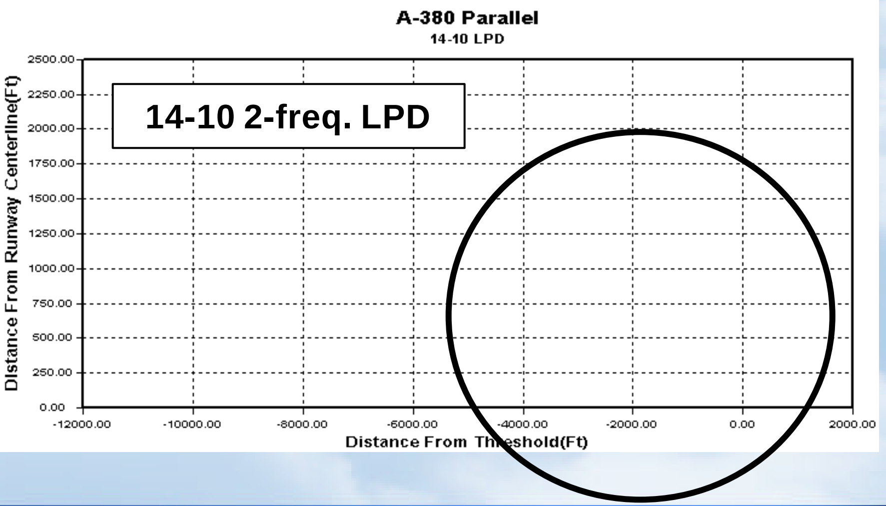




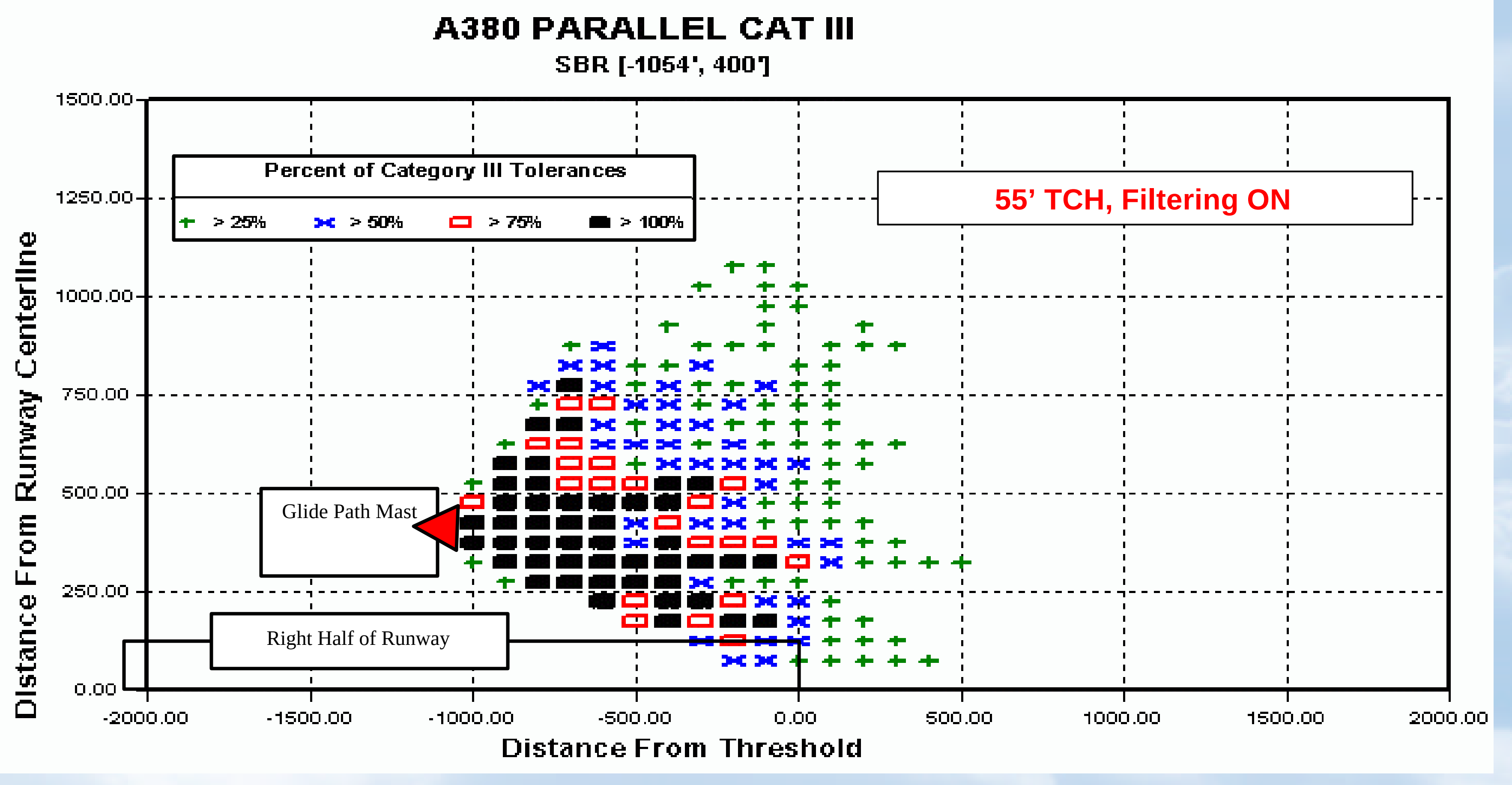
Percent of Category III Tolerances

> 25%   > 50%   > 75%   > 100%

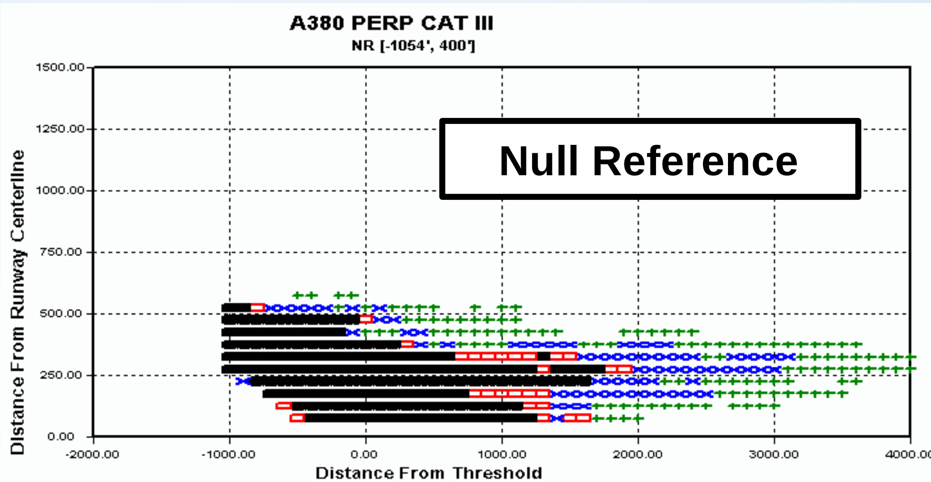
6.00 Degree C.W., A380 Parallel to Runway, 55' TCH, Filtering OFF

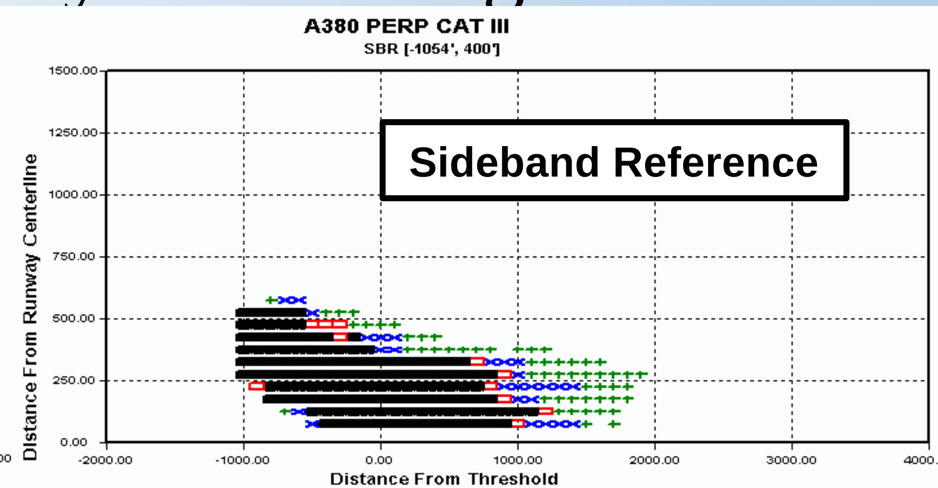


Sample Glide Path Result



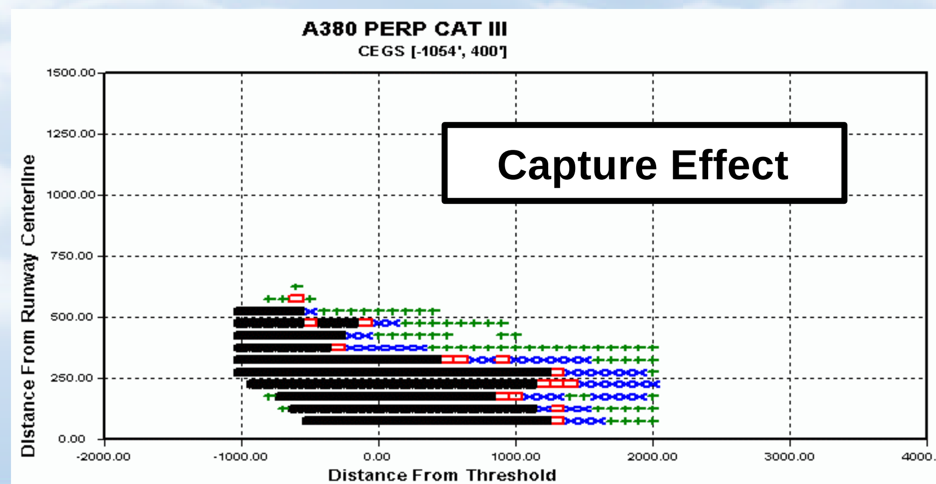
Effect of Different GP System Configurations





Percent of Category III Tolerances

> 25%   > 50%   > 75%   > 100%



55' TCH, Filtering ON

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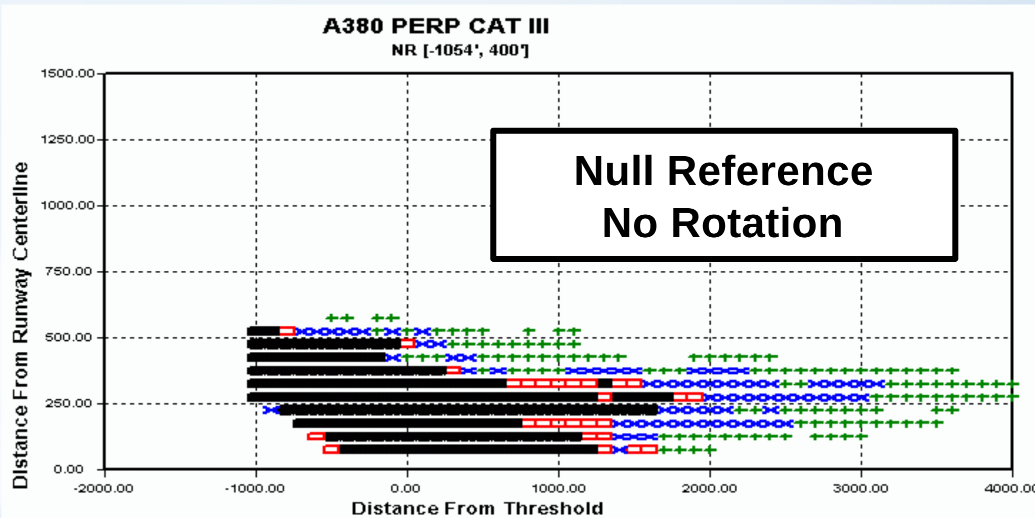
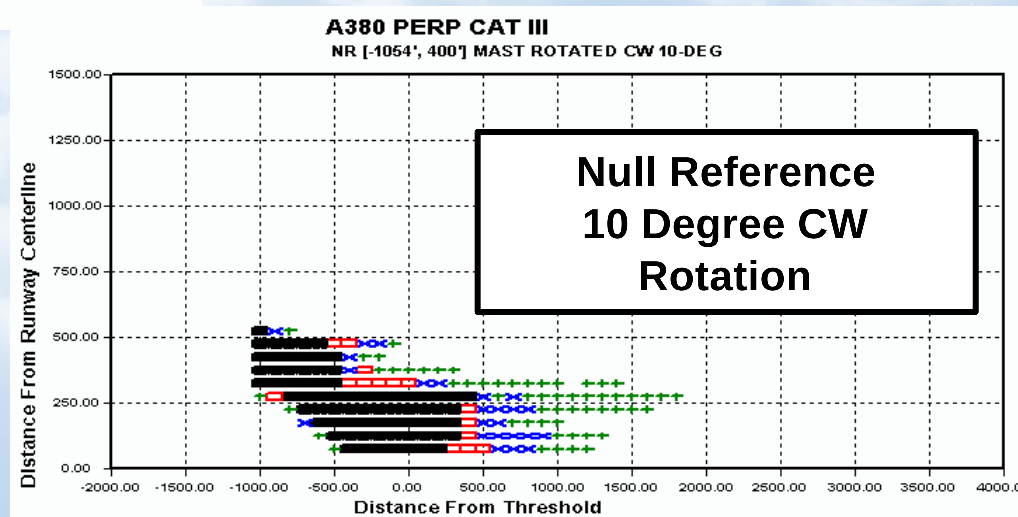
Effect of Rotating Antenna Bore Site



Percent of Category III Tolerances

> 25% > 50% > 75% > 100%

55' TCH, Filtering OFF



Application - Memphis FedEx A-380

- Modeling results were used to define airport design and operational constraints.
  - How far between new parallel taxiway and Runway 36R?
  - Where should GP hold lines be placed?
- A-380 degradation is larger than for B-747
- With A-380 on parallel taxiway near GP …
  - No degradation exceeds 100% for taxiway offset of 700’ or more (maximum was 25%)
  - Majority of roughness in last half mile prior to runway
  - No Path Angle Change (0.01 degrees)
- Hold line setback distances of 650’, 600’, and 550’ were defined for taxiway offsets of 380’, 480’, and 480’ respectively.

Modeling Results Summary

- General observations for CA/SA dimensions
  - Antenna horizontal patterns [polar coordinate system] evident
  - Off-azimuth radiation of 2-frequency arrays has little influence
  - Aircraft positions in last half of runway not important for Category I applications
  - GP lateral dimensions most affected by antenna beamwidth and bore site angle, fuselage length
  - GP longitudinal dimensions most affected by vertical antenna pattern
- Data now available to define maximum CA/SA dimensions for all aircraft types, all U.S. antenna system types, and all relevant parameters

Critical Area Operational Issues

- Although boundaries can now be defined from modeling data, six operational issues illustrate policy issues that must be addressed first.
  - Critical area protection
  - Taxiway positioning
  - New Applications
  - Aircraft size classification system
  - Static derogation of ILS guidance
  - Conservative boundary definition

#1 - Critical Area Protection - a

- Regardless of size, US Critical Areas are managed operationally by ATC personnel.
- ATC Handbook states, "[Protect the critical area for an arriving aircraft]...
  - When conditions are less than reported ceiling 800 feet and/or visibility less than 2 miles, except [for]:
    - A preceding arriving aircraft on the same or another runway that passes over or through the area while landing or exiting the runway.
    - A preceding departing aircraft or missed approach on the same or another runway that passes through or over the area.

Good Weather Exception

Preceding Aircraft Exception

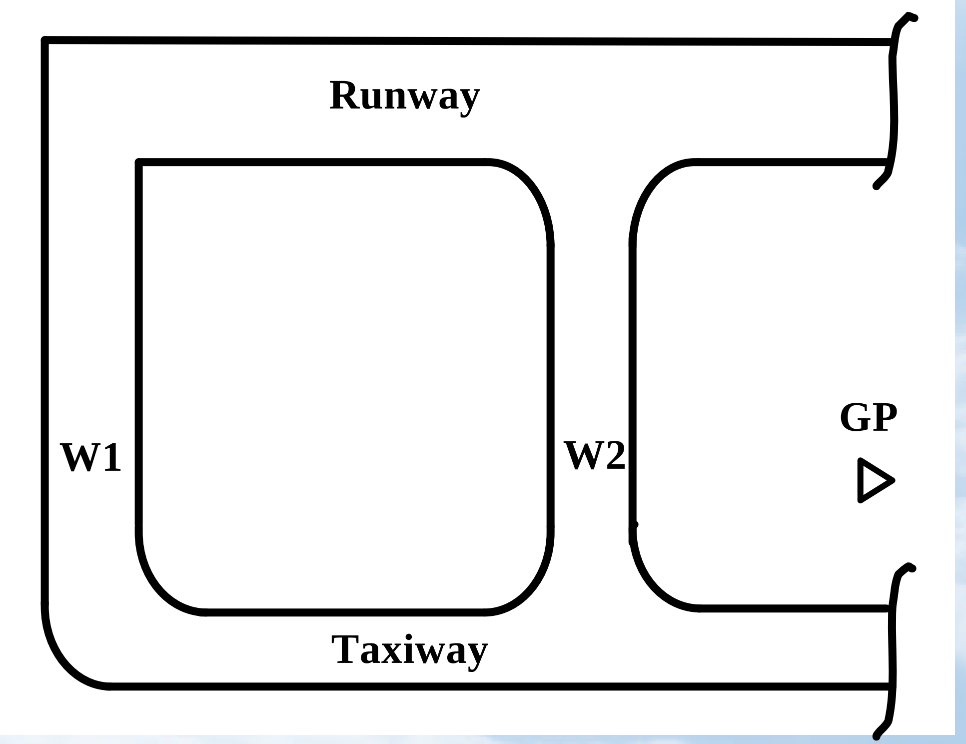
Departing Aircraft Exception

#1 - Critical Area Protection - b

- The “weather” exception was created many years ago (circa late 60’s), when...
  - Aircraft were smaller (“big” was B-707)
  - Category II and III operations were relatively rare
  - Autoland operations weren’t yet available
  - Airports were less congested
- Result: Few operational problems arose from this exception
- Conditions are much different now
- Because of the 3 exceptions, the inner portion of the US critical area, for which ICAO restricts aircraft for ALL ILS operations, is often not protected.

#2 - Taxiway Positioning - a

- Recent trend in airport design -- 2nd connector taxiway between parallel taxiway and runway, but IN FRONT OF GP antenna
- Purpose -- allow departures around "stalled" aircraft

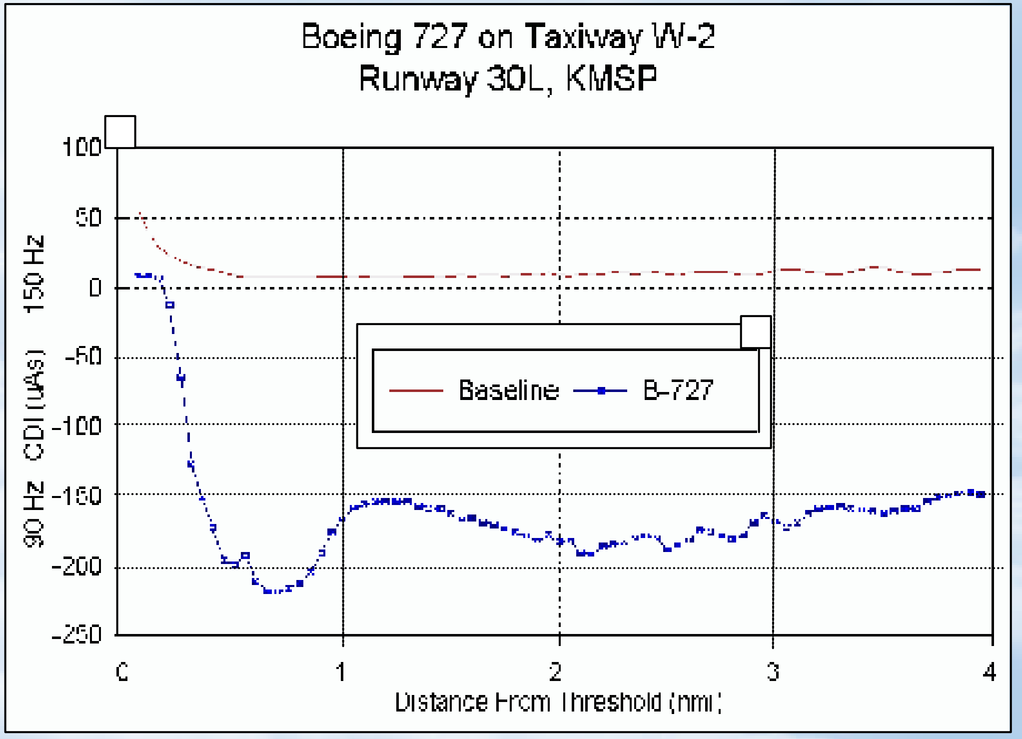


#2 - Taxiway Positioning - b

- Consider 2nd connector taxiway and the exceptions to critical area protection
- Numerous user complaints result
  - Even if 1st aircraft is below the cloud ceiling, 2nd and 3rd landing aircraft still in clouds, suffer erratic guidance, autopilot disconnects at minimum
  - Large aircraft on closer connector actually blocks the signal from GP to landing aircraft -- descent angle can be grossly low

#2 - Taxiway Positioning - c

- Minneapolis Runway 12/30 - pilot complaints of too-low approaches
- FAA flight measurements confirmed low path angle exceed tolerance by 600%, even with B-727.



#3 - New Applications - a

- Simultaneous Offset Instrument Approaches (SOIA)
- Purpose -- provide dependent instrument approaches to runways too closely spaced for independent approaches
- Require one straight-in (typically Cat III) ILS, and an offset ILS (with GS)
- Approach minima on offset ILS are high, to enable a VMC turn to the too-closely spaced 2nd runway
- San Francisco, Cleveland, ...

#3 - New Applications - b - Example 1

#3 - New Applications - c - Example 2

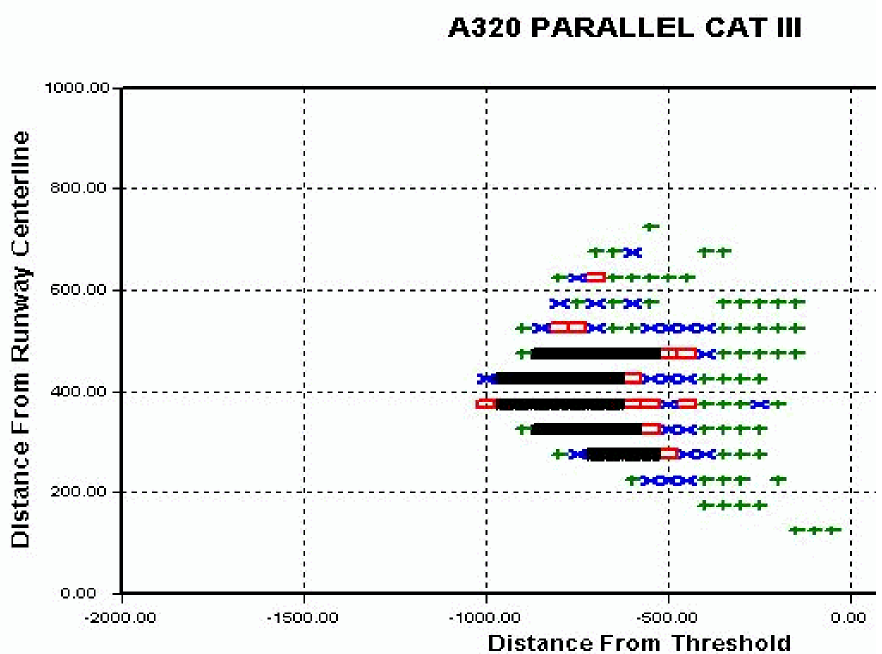
#4 - Aircraft Classification System

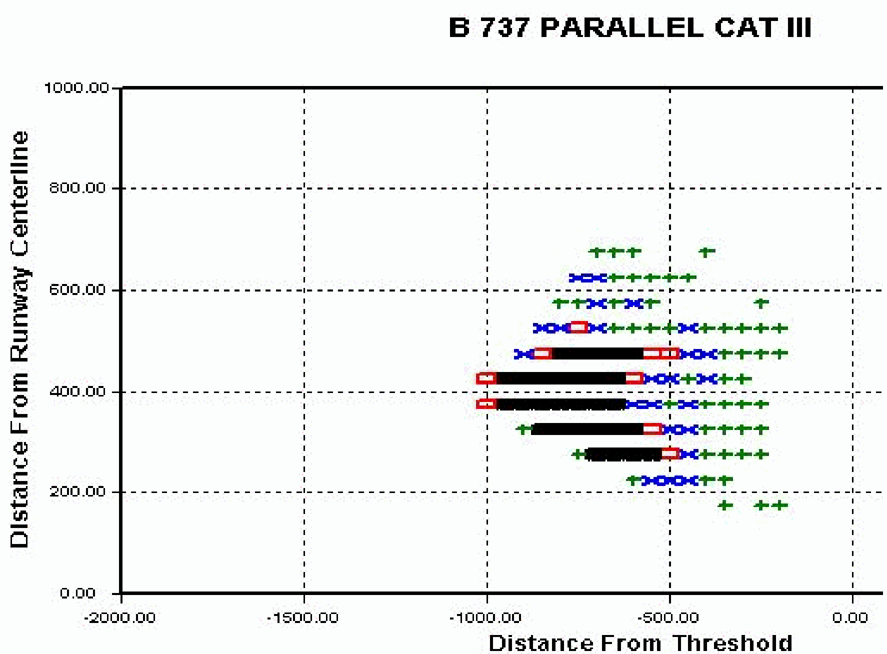
- Existing classification is too “course”
- Aircraft with similar reflection effects are classified differently, resulting in overly-large critical areas for some airports.
  - A-320 tail height = 38.7’
    B-737 tail height = 36.5’
  - A-320 “large”
    B-737 “medium”

Class	Tail Height (ft)	Conditional	Fuselage Length (ft)
Small	<20	OR*	<60
Medium	<38	OR*	<160
Large	>38	OR	>160
*Proposed to become “AND”			

#4 - Aircraft Classification System

- Even though the effects of these large and medium aircraft are essentially identical …
- An airport operating aircraft no larger than A-320 must protect critical areas sized for B-747 and larger aircraft!





#5 - Static Derogation of ILS Guidance - a

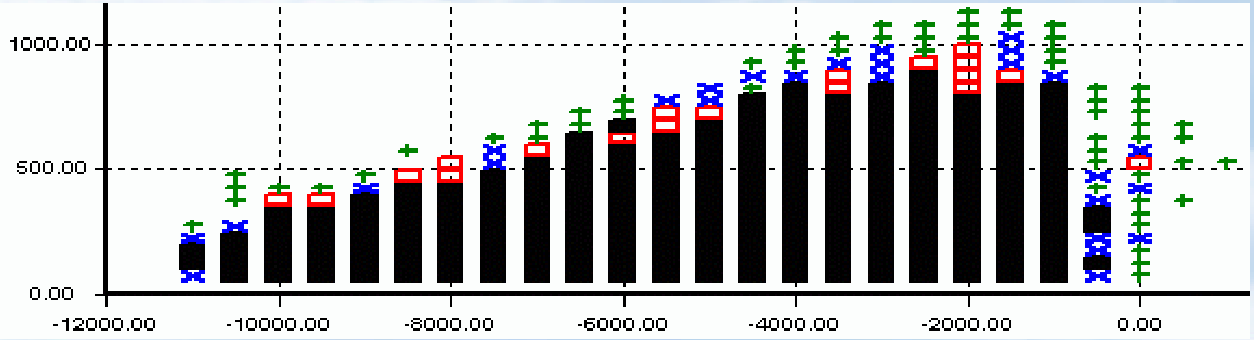
- ICAO makes clear that critical [and sensitive] areas should be ILS-specific:

  "If the course structure is already marginal due to static multipath effects, less additional interference will cause an unacceptable signal. In such cases a larger-size sensitive area may have to be recognized."

- Existing U.S. practice is to define critical area sizes at 100% of the tolerances, ignoring any static multipath.
- ICAO recommends combining static and dynamic multipath using the *rss* technique.
  - Assures total derogation does not exceed 100%, but ...
  - Results in runway-end-specific critical area sizes, which will also change over time.

#5 - Static Derogation of ILS Guidance - b

- Method is needed to provide for static multipath with standardized CA/SA sizes and few changes over time.
  - FAA engineers regularly analyze effects of proposed construction on airports
  - If effects exceed ~50-60% of tolerances for Category II/III, proposal is modified
  - Result: Static ILS beam quality seldom exceeds 60%
- Since most Cat II/III ILS signals are <= 60% of tolerances, sensitive areas can be defined at 80%, rather than 100%, of tolerances.
  - Implements ICAO recommendation - RSS of <60% and 80% is <100%
  - Practical, since 80% SA boundaries not greatly larger than 100%
  - Resulting SA is fixed in size and over time, with rare exception



#6 - Conservative Boundary Definition

- Current US CA/SA boundaries defined by using:
  - Largest aircraft expected at that airport
  - 3.00 degree course width, regardless of runway length
- Both techniques penalize airports
  - Single set of hold lines positioned for largest aircraft
- Multiple hold lines (e.g., large aircraft, small aircraft) would solve this, but with increased implementation complexity.

Operational Issues Summary

- Each of six issues requires substantive policy changes to solve
- Some of the issues demand …
  - larger protected areas
  - or more diligent protection during low visibility weather
- Others will reduce required sizes.

Conclusions - a

- U.S. and ICAO critical [and sensitive] area policies different in several key respects.
- U.S. critical area sizes are overly conservative for some applications.
- U.S. critical area definitions rely on an inappropriate aircraft classification system.
- Current U.S. critical areas are not adequately protected under some operational conditions.

Conclusions - b

- Current U.S. critical area sizes are independent of individual ILS static beam quality.
- New aircraft, ILS antenna systems, and operational conditions require a revision to U.S. critical area policy and procedures.
- New aircraft types and ILS antenna systems have been modeled for the purpose of defining new critical [and sensitive] area boundaries.

Conclusions - c

- Before the new data can be used, several key policy decisions must be made.
- Static ILS beam quality can be taken into account without adopting runway-specific protected area sizes, by defining appropriate critical and sensitive areas, and fully protecting the critical area during any ILS operations.
- Critical and sensitive area sizes may be reduced by several readily available techniques.

Recommendations - a

- Modify the aircraft size classification system, for purposes of defining critical [and sensitive] areas, to focus primarily on tail height. Change the tail height break point from 38' to 40'.
- Promote construction of second connecting taxiways behind, rather than in front of, the GP mast.
- Define critical [and sensitive areas] in a polar coordinate system, to the extent feasible, with origin at the relevant ILS antenna system.

Recommendations - b

- Adopt the ICAO critical and sensitive area concept, to replace the current critical-area-only concept.
  - Prohibit any vehicles or aircraft in the critical area, during ANY (e.g., to include good visibility) ILS operation.
  - Restrict aircraft from the sensitive area whenever reported weather conditions are worse than a defined threshold (currently 800’ ceiling and/or two miles visibility) and a landing aircraft relying on the ILS is inside the final approach fix.
  - If an aircraft is using the ILS during weather conditions better than defined above, and an aircraft is in the sensitive area, notify the using aircraft of the sensitive area violation, and assure the weather conditions do not deteriorate during the approach without advising the aircraft on approach.

Recommendations - c

- Define protected area boundaries for each aircraft classification size as follows:
  - Define critical area boundaries equal to those defined by ICAO, or larger if required to protect 100 per cent of alignment tolerances.
  - Define minimum sensitive area boundaries such that no more than 80% of tolerances (i.e., alignment, bends, and roughness) are consumed for each Category of Operation. This allows for static multipath of up to 60% of tolerances, using the root-sum-squared technique.
- Additional recommendations are presented in the paper.

Future Work

- Given FAA policy decisions ...
  - Determine boundaries of critical and sensitive areas -- shape and size
  - Define changes needed in FAA documents
  - Consider additional aircraft orientations
  - Advance methods to reduce CA/SA sizes
    - More detailed modeling methods
    - Advanced ILS antenna systems
    - Consider signal processing available in advanced avionics

Acknowledgement and Closing

FAA ILS Siting Handbook
Working Group,
which initiated this effort

Thank you for listening!

Questions?

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