

DESIGN AND OPTIMIZATION OF A MICROPHONE-PHASED ARRAY FOR FLIGHT TESTING

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OUTLINE

- **Background Information**
- **Purpose of the Project**
- **Array Design**
- **Test Results**
- **Summary/Conclusion**

BACKGROUND INFORMATION

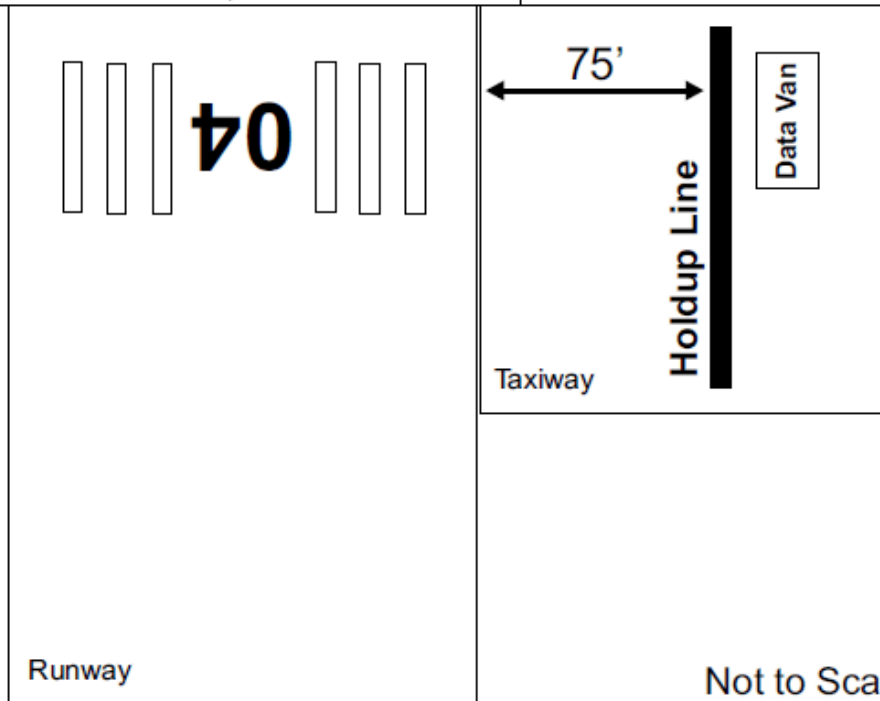
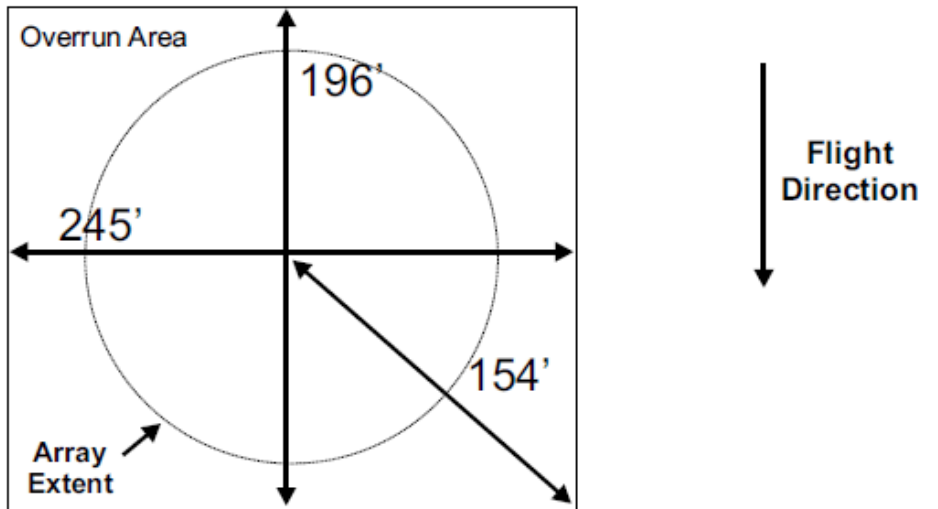
- **Flight test conducted at NASA Wallops Flight Facility in 2014**
- **Gulfstream G550 aircraft**
- **Variations in airspeed, flap deflection and landing gear deployment**



PURPOSE

- Obtain measurements of airframe noise using improved microphone-phased array
- Analyze results to better identify dominant noise sources in airframe
- Reduce impact of aviation on society by reducing airframe noise
- Environmentally Responsible Aviation Project

Array Test Site



Not to Scale



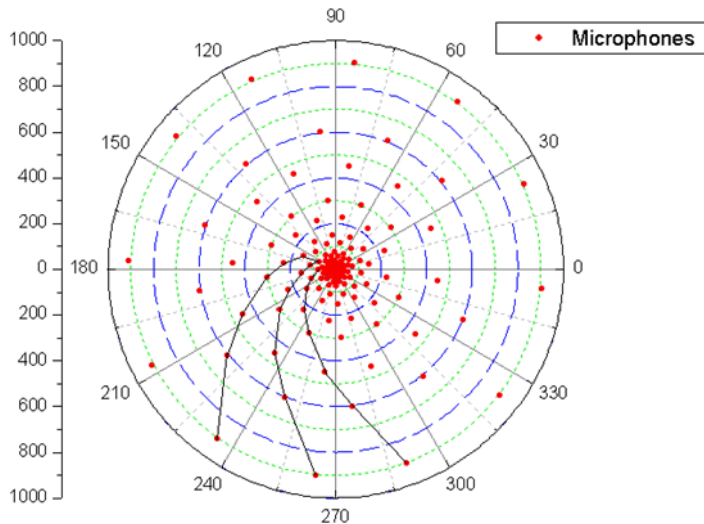
Runway

Array Deployment Location

BEAMFORMING

- **Beamforming used for localization of sound sources on moving objects**
- **Source localization (beamform) maps are mainly used to detect areas of dominant noise sources**
- **Good beamforming results rely on good array design**

ARRAY DESIGN



Previous Array Design

New design img
here

Previously:

- Non-uniform spiral clustering of 167 microphones
- 12 spiral arms
- 150 feet diameter
- 3 degree + random perturbations
- Provided sidelobe suppression of minimum 6 dB

Currently:

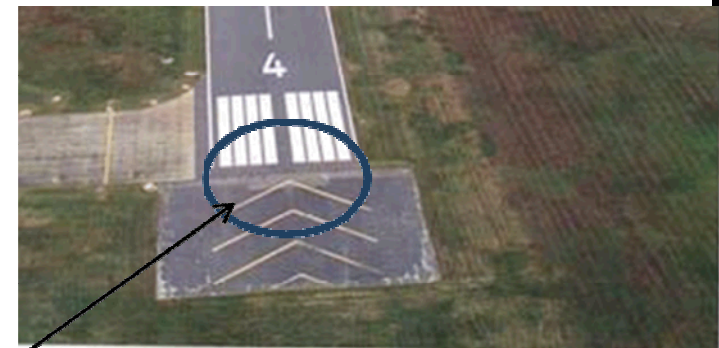
- Will utilize more space on the overrun area
- Minimum of 195 feet diameter
- 185 microphones
- Want to limit sidelobe levels to less than or equal to 6 dB w.r.t. main lobe

ROTATIONS, RANDOM PERTURBATIONS AND EXTENSIONS

rotation matrix

$$\begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} x\cos\theta - y\sin\theta \\ x\sin\theta + y\cos\theta \end{bmatrix}$$

- Tested design using $\Theta = 3$ and 6 degrees
- Also applied a random perturbation of ± 3 degrees to the rotation of each microphone
- Tested a bigger extension of the design with 220 feet diameter
- Requires array to be located partially on runway



Possible Array Deployment Location

SIDELOBE PERFORMANCE

Ideal array response: $W(k, \vec{x}, \vec{x}^o) \equiv \sum_{m=1}^M w_m \frac{r^o}{r_m^o} e^{ik[(r^o-r)+(r_m^o-r_m)]}$

where k = wave number, $\vec{x}$ = grid point location, $\vec{x}^o$ = source location, M = # of microphones, w_m = weighting on microphone m , r_o = source distance, r_m^o = mic to source distance, r = grid point to origin distance, r_m = grid point to mic distance

Plotted as: $dB(\vec{x}) = 20 \log_{10} \left[\frac{|W(k, \vec{x}, \vec{x}^o)|}{|W(k, \vec{x}^o, \vec{x}^o)|} \right]$

- **Must compute threshold for central peak by finding closest point to source at which dB difference is ≥ 3**
- **Can use Matlab function `findpeaks()` to locate the local maxima**
- **Can then select peak with largest SPL* and compute ratio**

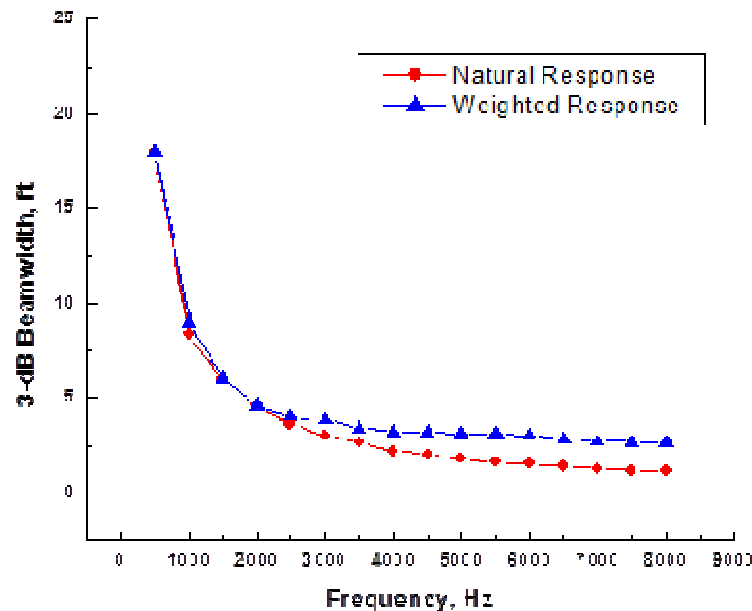
Peak-to-Sidelobe Ratio: $\frac{\text{Maximum Sidelobe SPL}}{\text{Source SPL}}$

WEIGHTING

$$w_m = 1.0 - 0.5(1.0 + \tanh(0.000025 * (freq * r_m - 200000.0)))$$

where $freq$ = beamforming frequency

- Necessary for a more consistent beamwidth
- Weighting is solution to de-correlation of outer microphones at higher frequencies

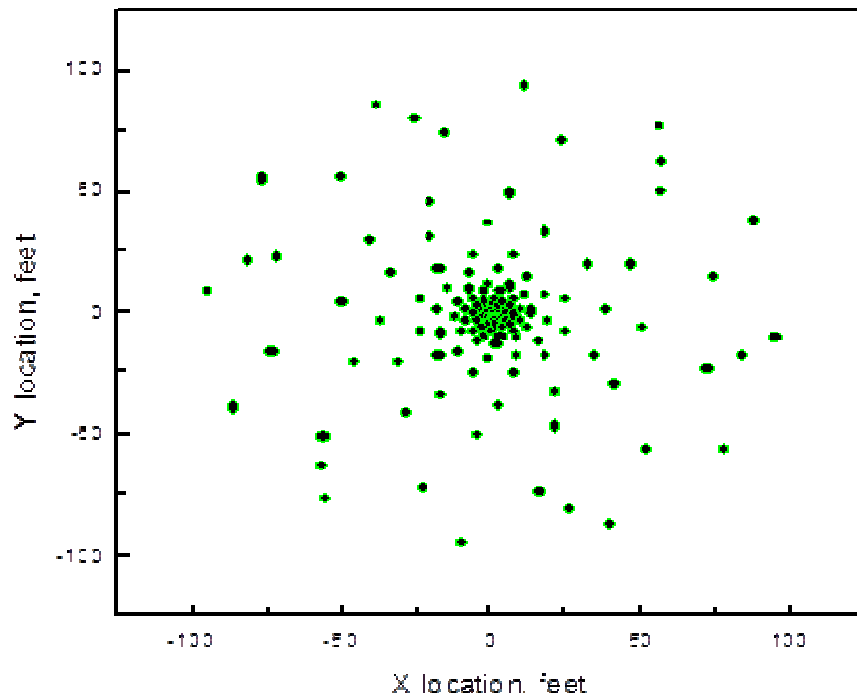


Results from 2006 Flight Test

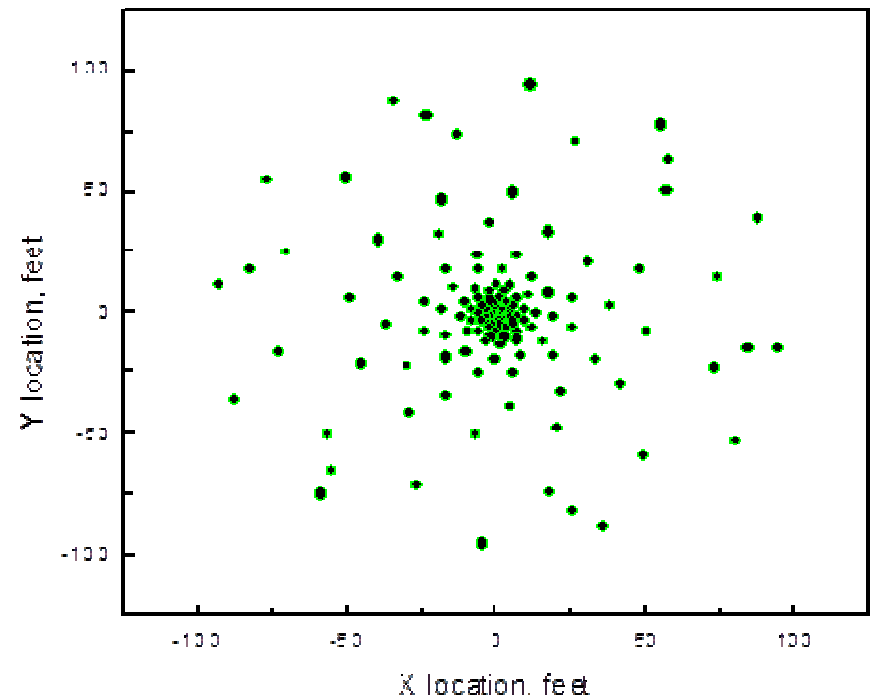
RESULTS

- **Coarray**: a geometric computation of distances between pairs of microphones
- Two points on top of each other undesirable

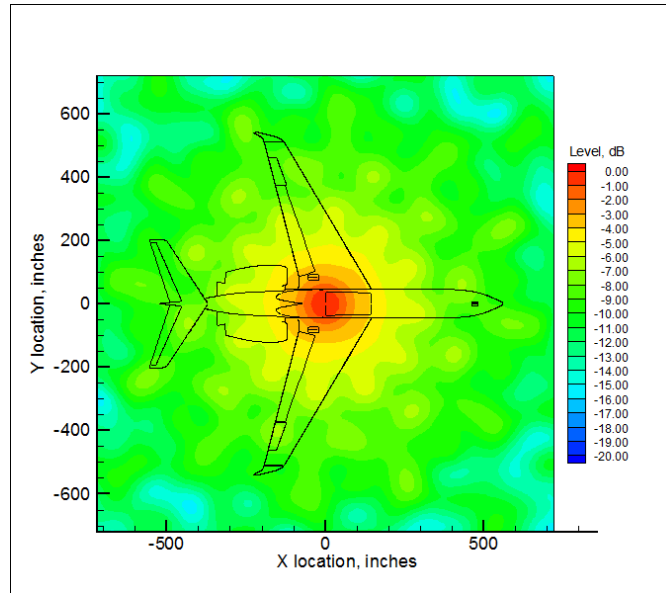
6-Degree Spiral Design



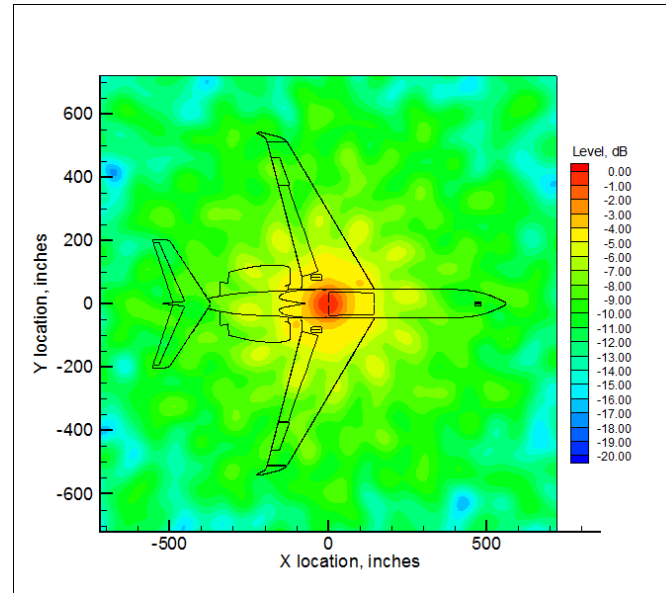
6-Degree Spiral Design With Random Perturbations



➤ **Low Frequency Performance Comparison:**

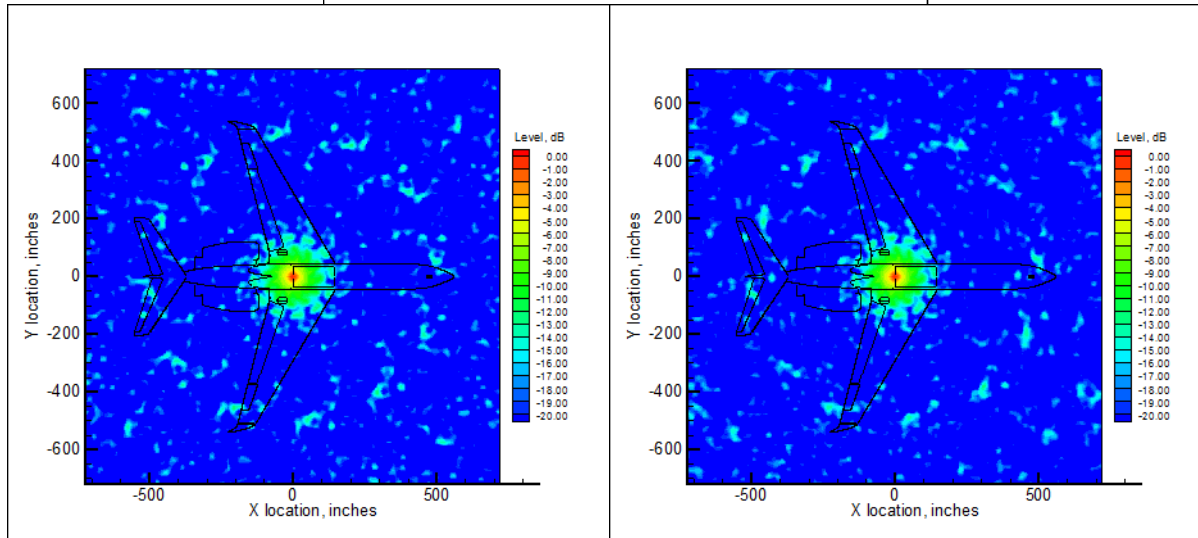
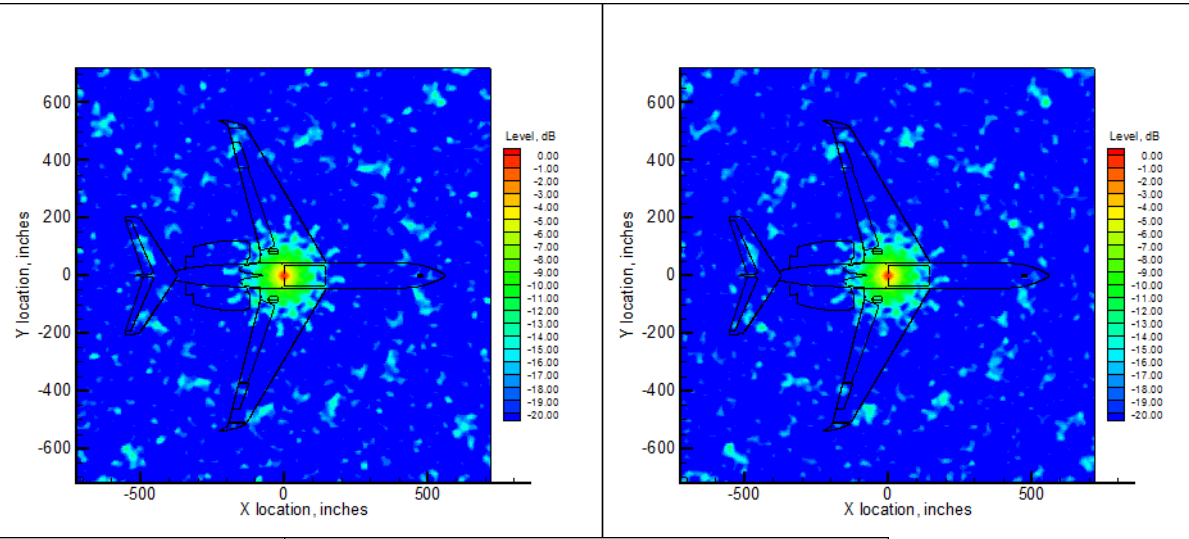


2006 Design



Current Design

- **Additional rings of microphones have improved response by approximately 30-40%**



Insert bigger design
results here

Top Row: 3-deg spiral, 3-deg spiral + rand
Bottom Row: 6-deg spiral, 6-deg spiral + rand,

SUMMARY

- **Several good options for designs**
 - Acceptable coarray
 - Good low frequency response
 - Good sidelobe performance
- **Random perturbations improve results only slightly**
- **Decision regarding degree of arm angle comes down to aesthetics**