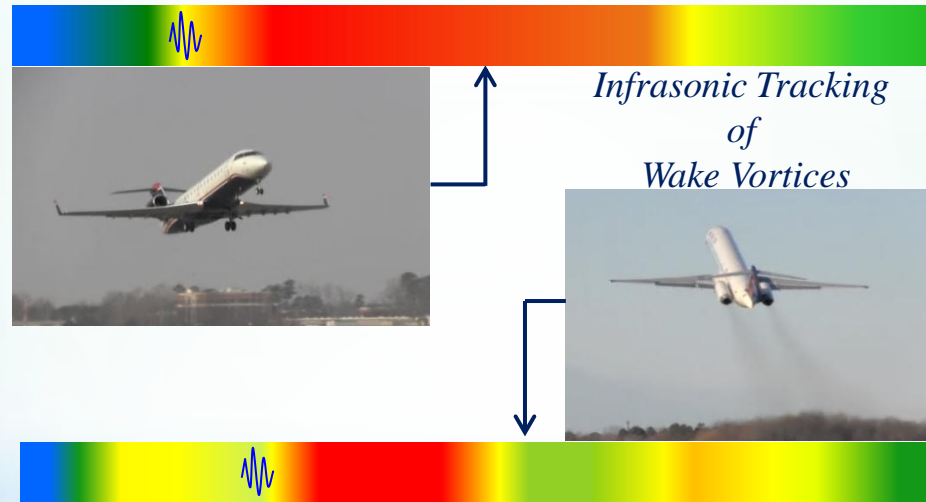


Wake Vortex Detection: Phased microphone vs. linear infrasonic array



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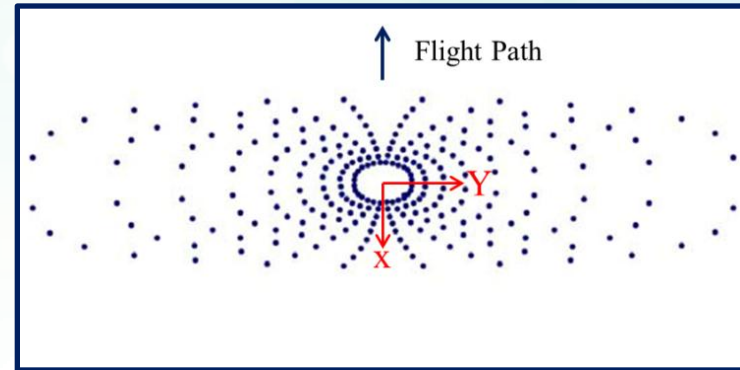
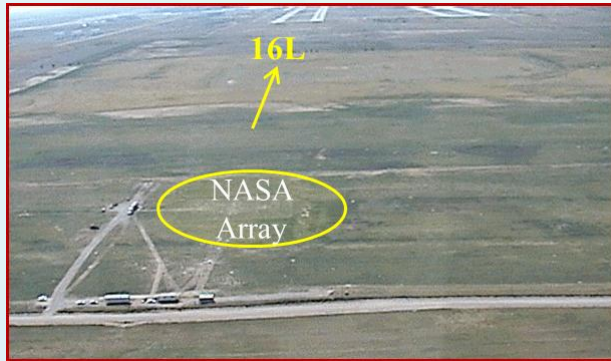
WakeNet-Europe 2014, Bretigny, France
May 13-14, 2014

Outline

- Overview of Phased Array Denver Test
- Data Collection at Newport News International Airport
- Infrasonic Data Analysis of different Aircraft
- Summary Chart
- Conclusions

2003 Phased Array Denver Test

- Sensors located about 2 miles from the Denver runway 16L.
- 252 Panasonic WM-61A Microphones.



- Array deployed in 400 by 150 feet area.
- The tests were performed only on landing aircraft.
- Landing aircraft altitude was 600-700 feet over test site.

2003 Phased Array Denver Test

- It was assumed for these tests that most prominent wake vortex noise can be heard only during landing approach (sound when wake vortices interact with the ground).
- Out-of-ground-effect (OGE) wake vortex noise is a hollow, low-frequency, howling sound after an aircraft passes overhead, and continues for more than a minute.
- It was presumed for these tests that aircraft also generate wake noise during takeoff conditions, but it was difficult to measure the vortex sound due to interference by the jet noise.
- Given limitations of phased microphone array (microphones were not suitable to detect low frequency sound), the target was only to detect audible sound.

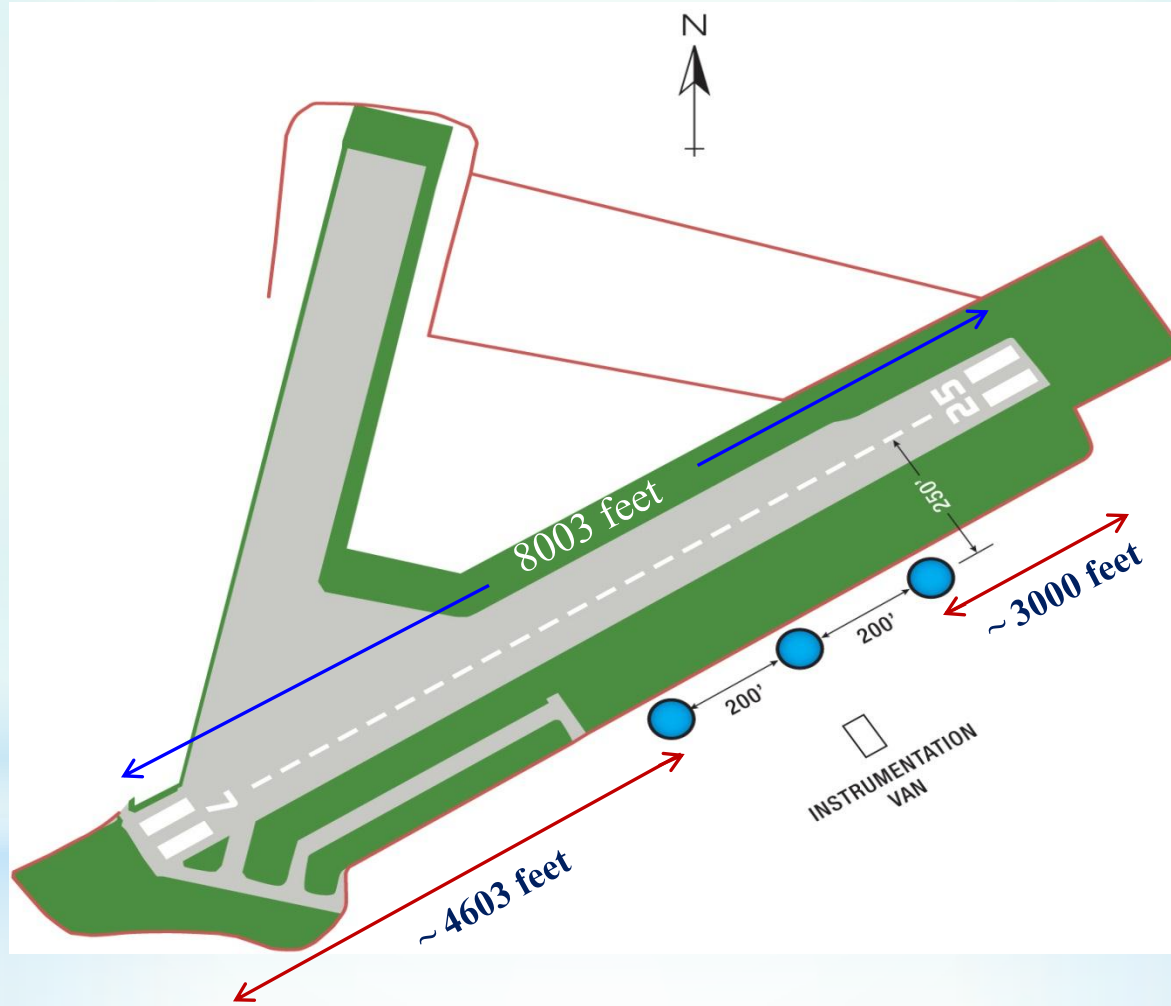
Limitations of the Phased Array Microphones

- Due to the vent, the microphone is not suitable for infrasonic measurements.
- The set-up was to record synchronized data but there was offset from one board (8-channel per board) to the next.
- Due to sensitivity issues of the microphones, the gain had to be adjusted after the first 15 seconds of the recording.
- In post-processing it was found that gain settings were too high for many of the runs, leading to clipping.
- The microphones were packaged in plastic bags but the effect of the bag on low frequency (100 Hz) response was unknown.

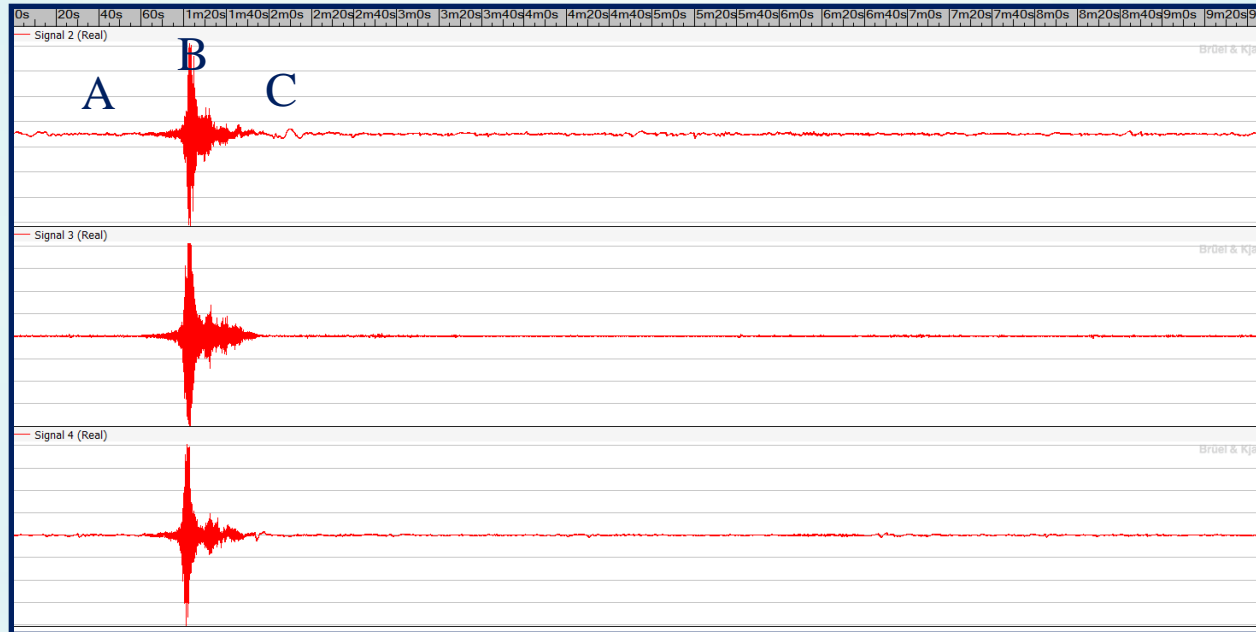
Phased vs. Infrasonic Microphone

Specifications	Phased Microphones	Infrasonic Microphone
Power Consumption	5 mW	35 mW
Sensitivity	6 mV/Pa	400 mV/Pa
Phase, deg (1 ~ 100 Hz)	Within 40° (10 samples)	Within 7° (4 samples)
Self Noise dB (@ 0.1 Hz)	Not Suitable for Low Frequency	-84.2 dB
Self Noise dB (@ 1 Hz)	Not Suitable for Low Frequency	-104.5 dB
Self Noise dB (@ 100 Hz)	Not Suitable for Low Frequency	-129.6 dB
Field Calibration	No	Yes
Location Limitation	Yes	No
All Weather	No	Yes

PHF Airport Runway (7, 25)



“Burst”: A Reliable Time Stamp



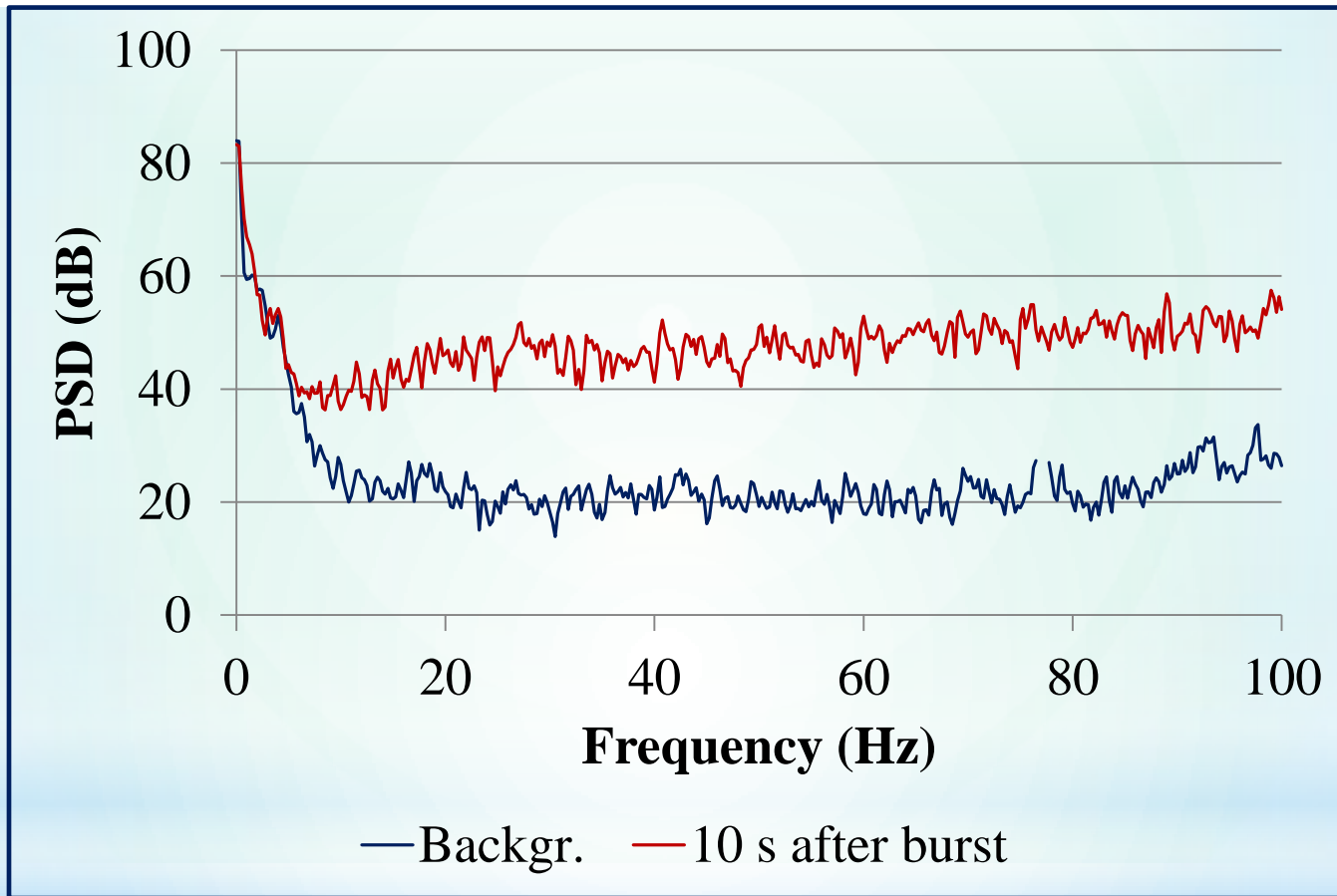
The pressure signals received at the three microphones fall into three regions (A, B, & C).

On takeoff: **Region A**: Aircraft is accelerating toward takeoff.

Region B: Aircraft passes microphones and takes off, producing large hydrostatic pressure, called a “burst,” which serves as a reliable time stamp.

Region C: Aircraft is airborne, shedding wake vortices.

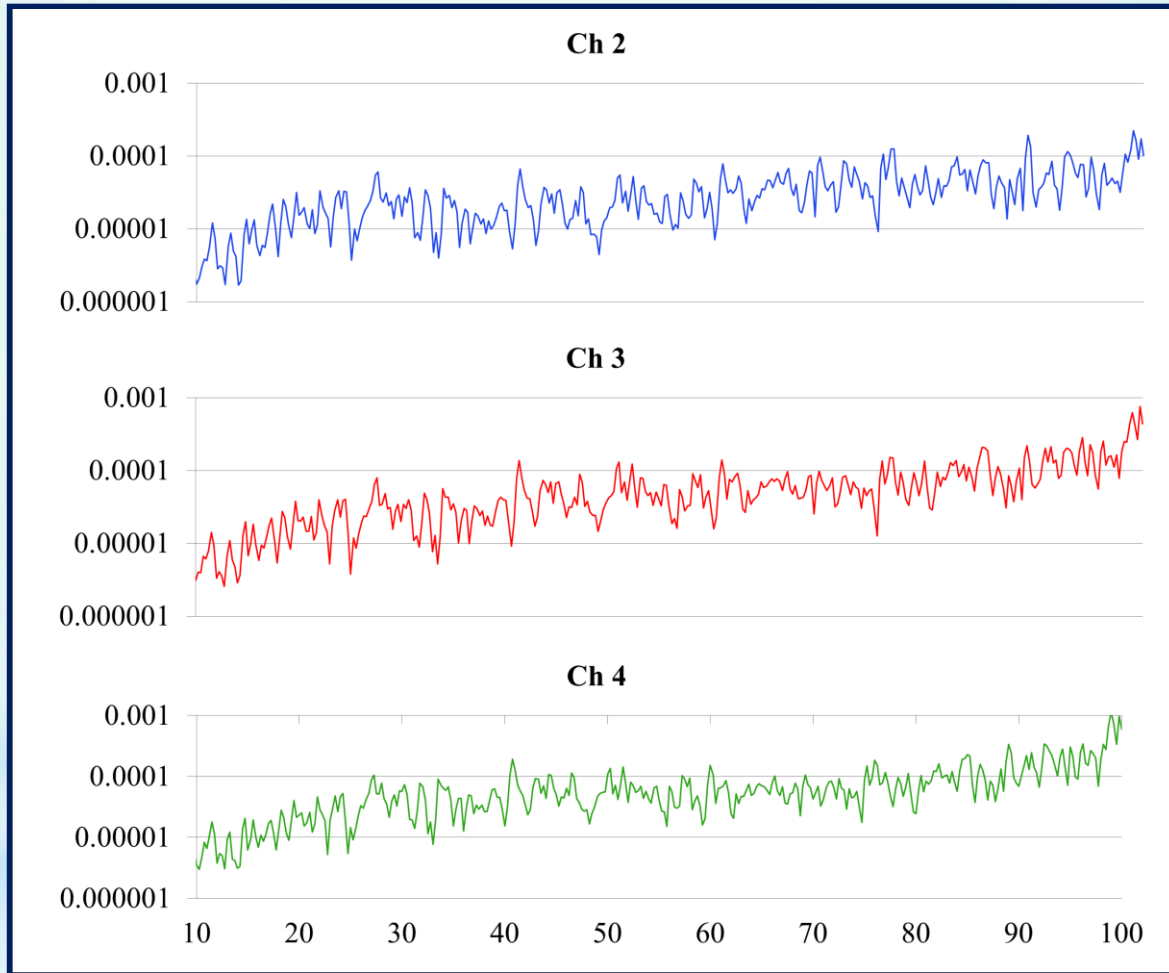
CRJ Takeoff auto-spectrum (Channel 2)



The microphone signals 10-s after takeoff (coherent) are more than 20 dB above the background (incoherent). Since the vortex emission spectrum appears similar to the background spectrum, we concluded that coherence is a better indicator of vortex presence than spectral level. The spectrum is broadband and reveals no features.

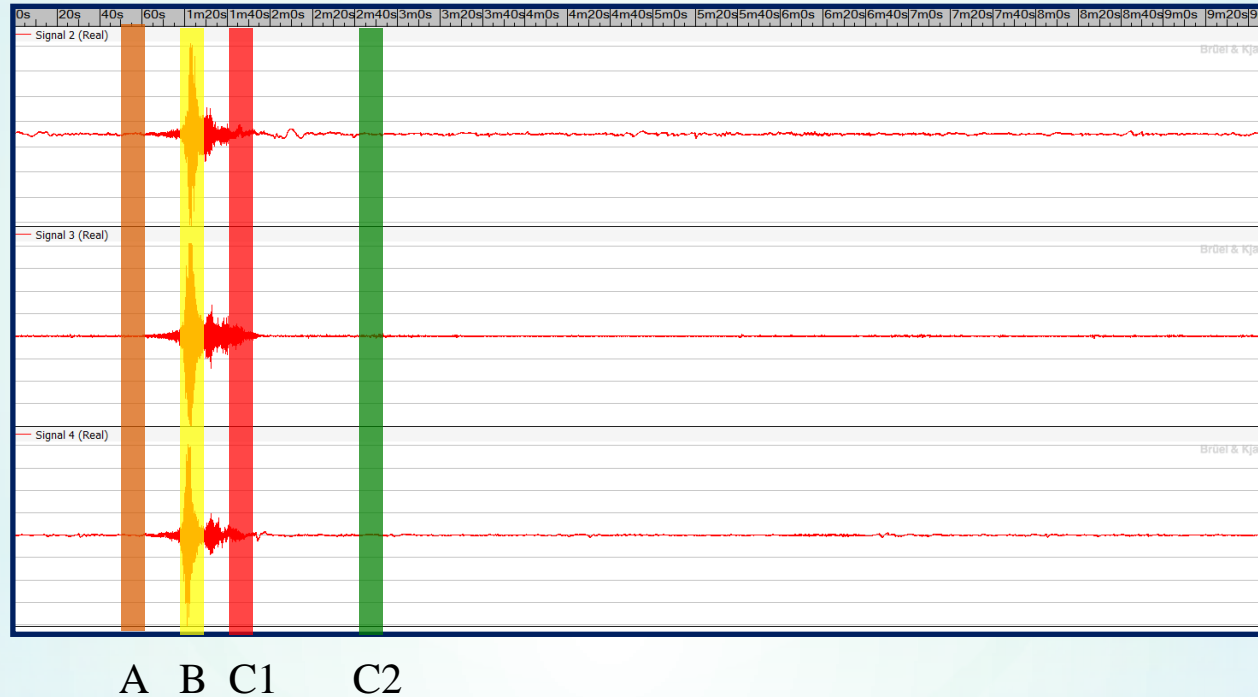
Autospectrum of Three Channels

Microphone Response (Pascal)



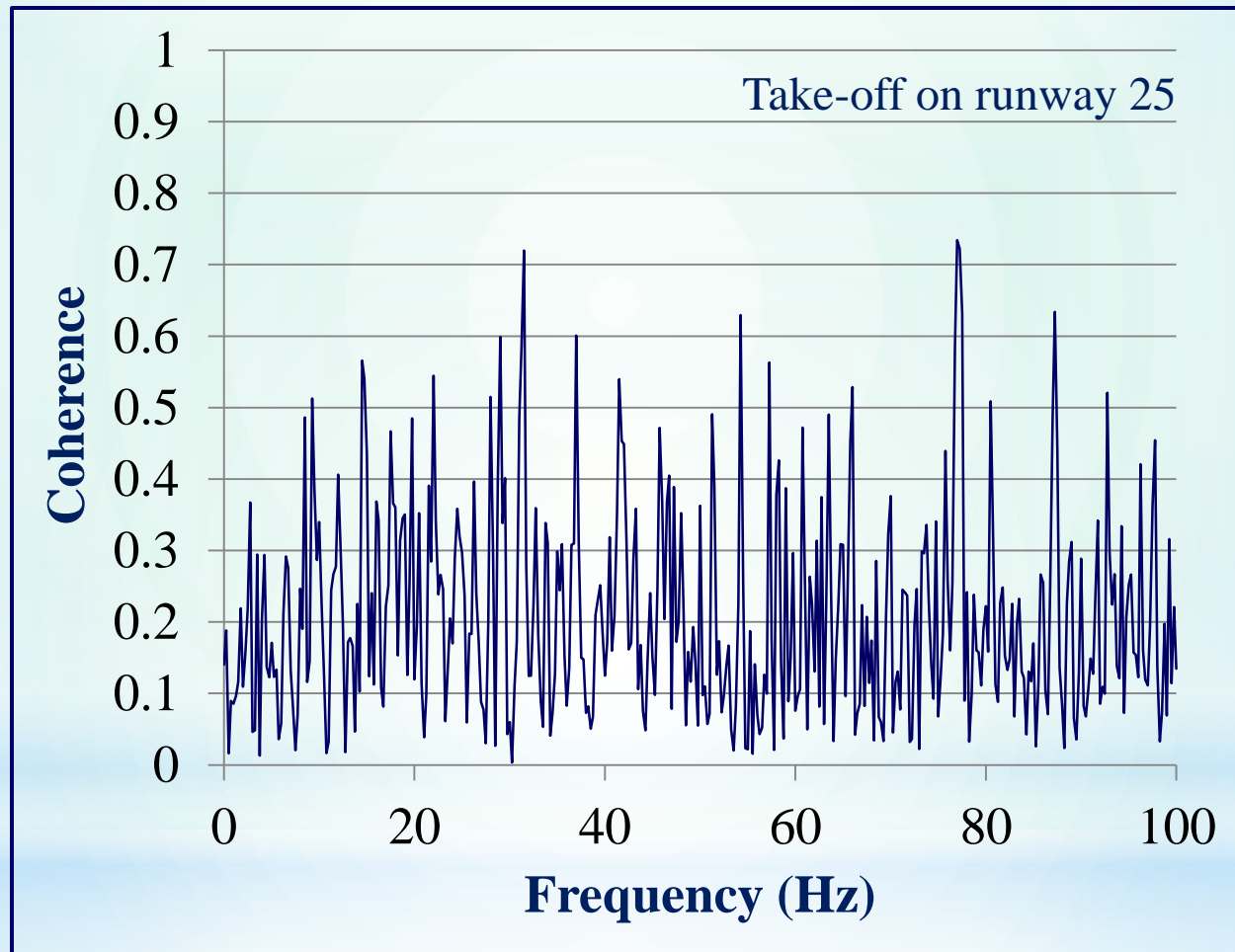
Frequency (Hz)

CRJ – Takeoff

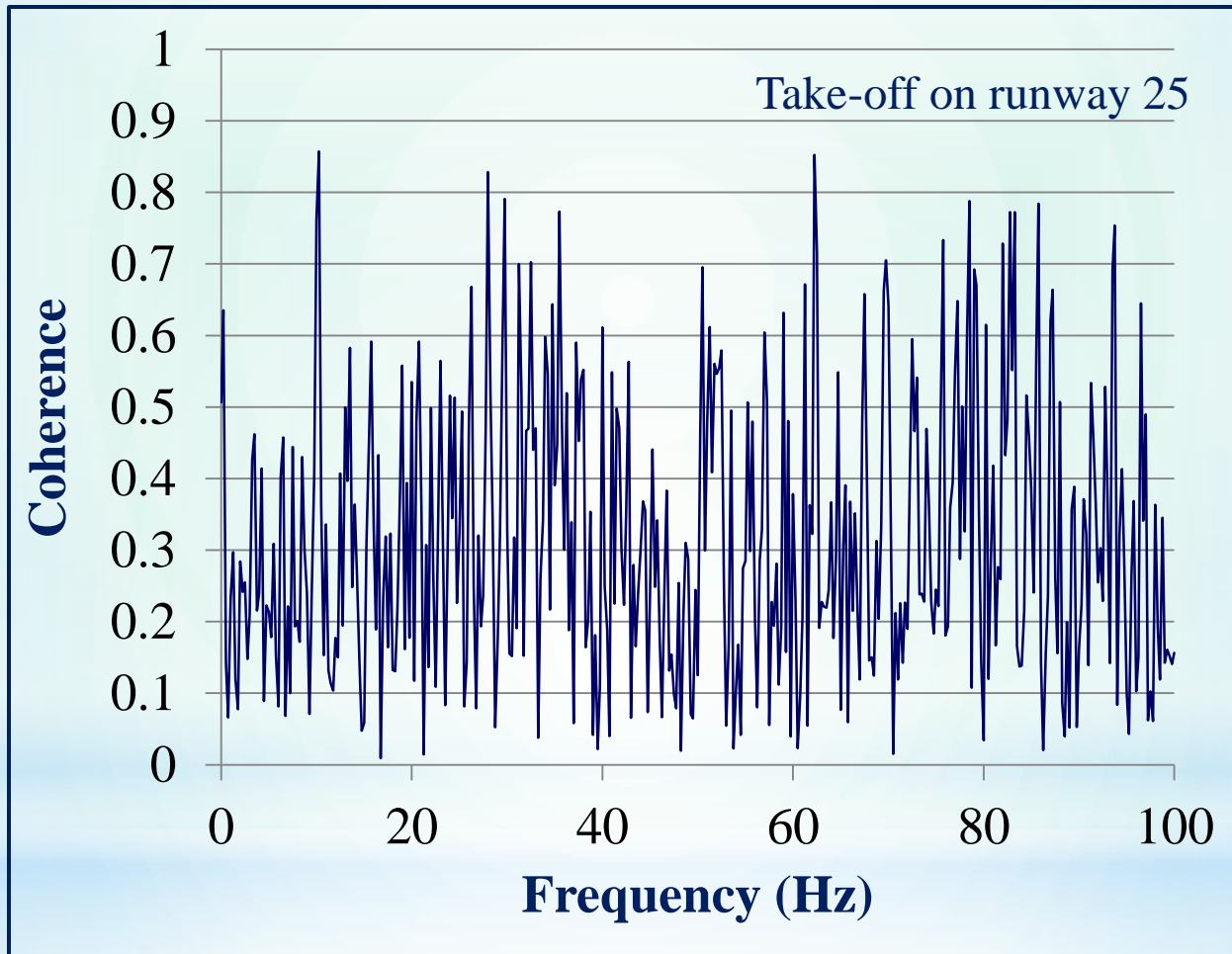


In this slide, the coherence spectrum on takeoff of CRJ is examined in 10-s intervals: prior to burst (brown), at instant of takeoff (burst, yellow), 10-s after takeoff (red), and 50-s after takeoff (Green).

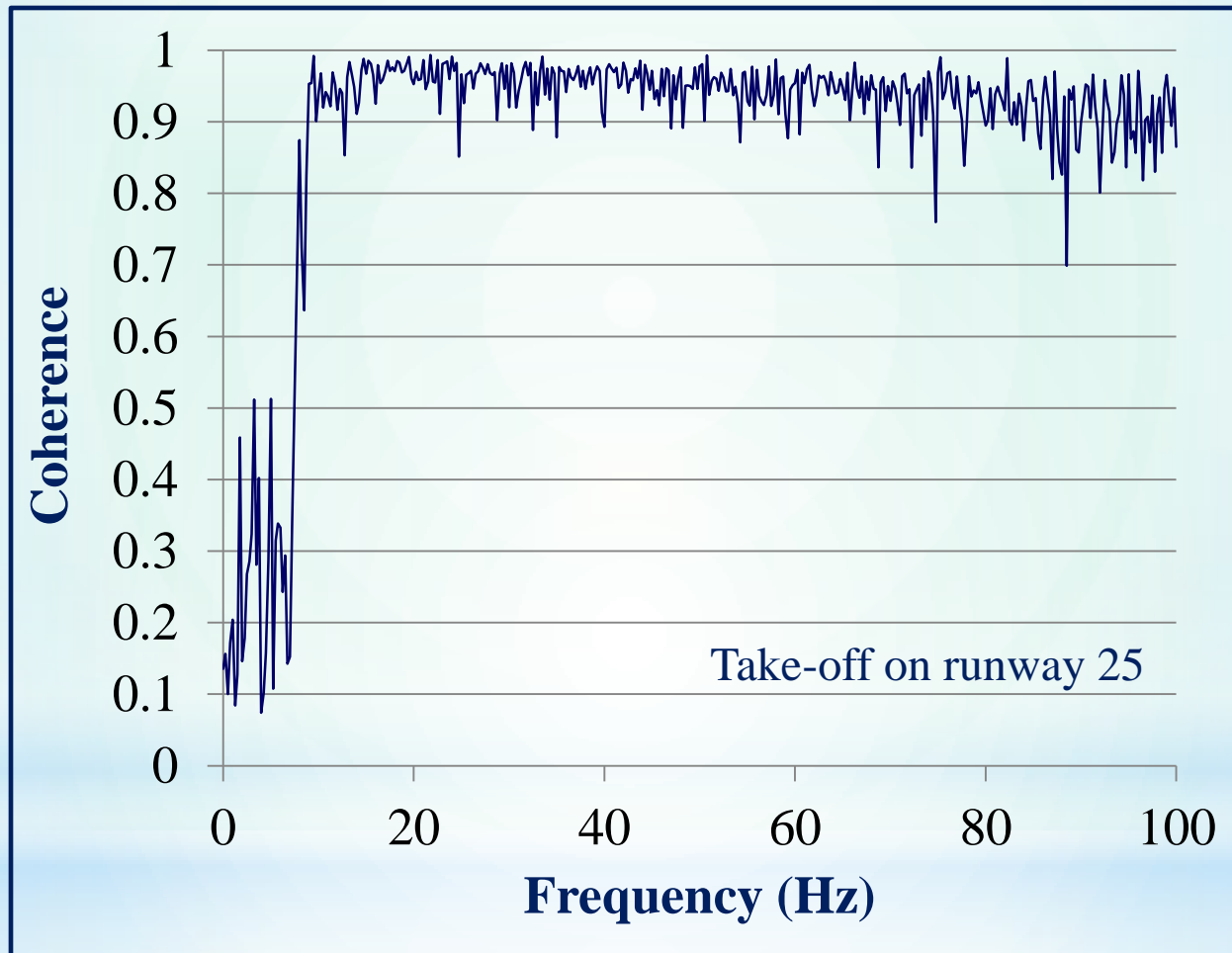
CRJ Takeoff Prior to burst – Region A



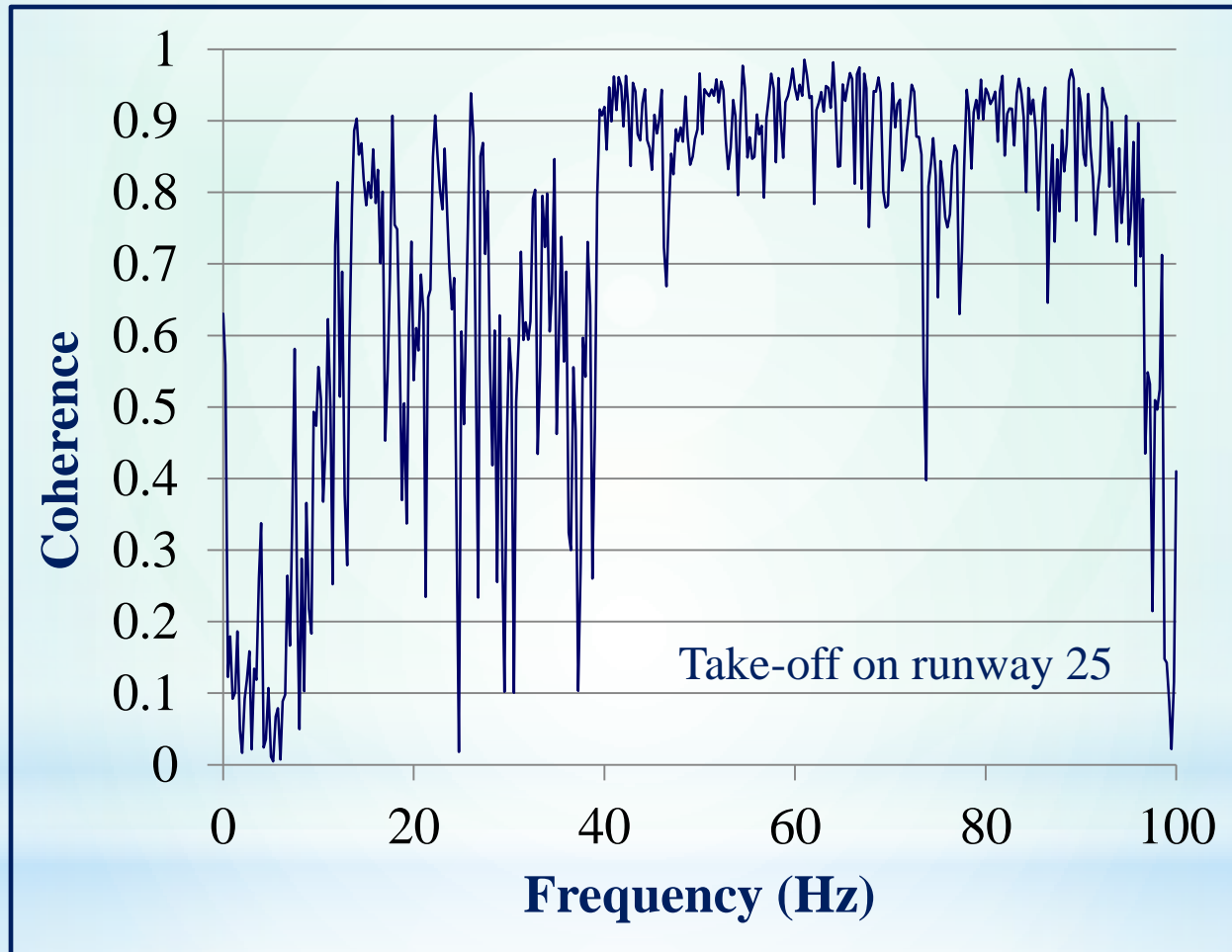
CRJ Takeoff during burst – Region B



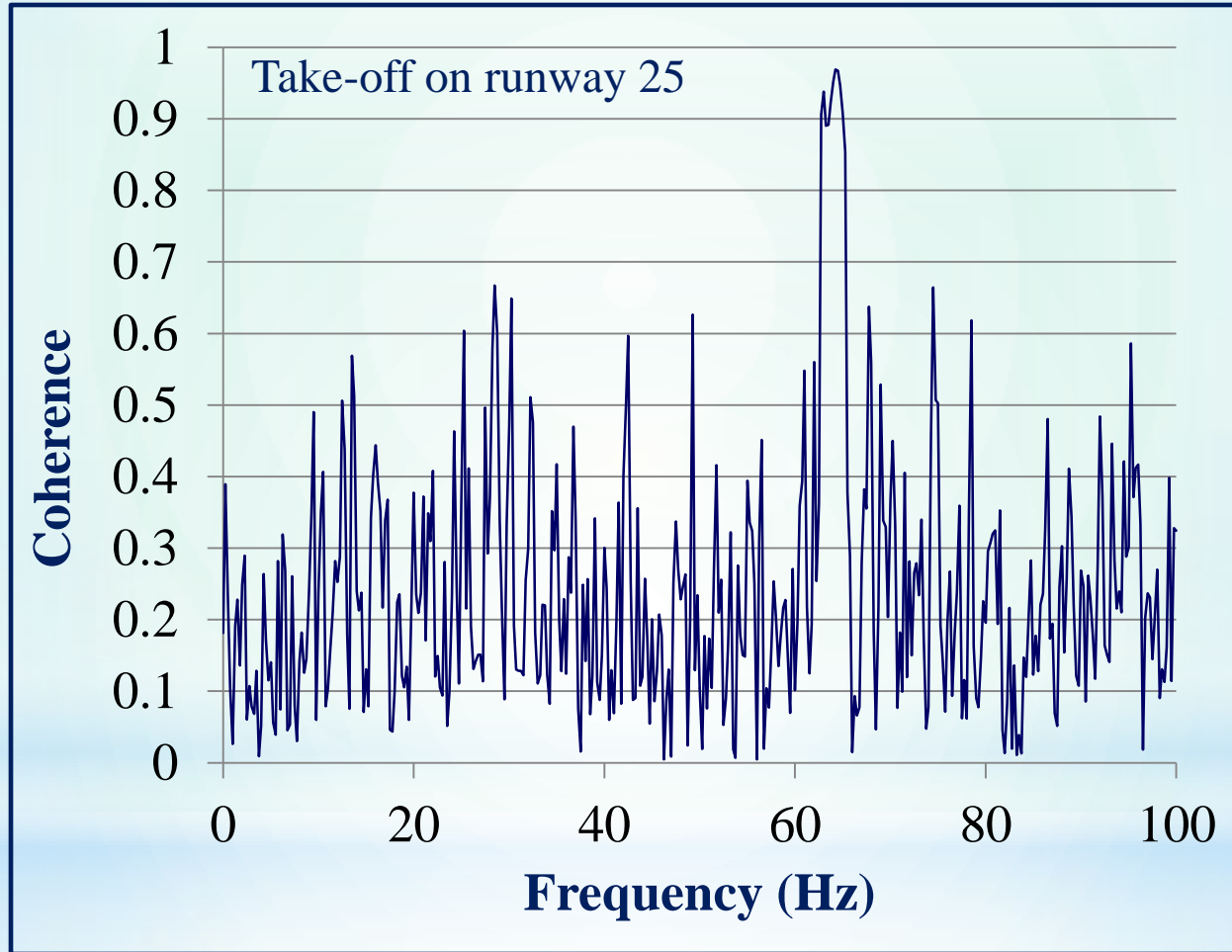
CRJ Takeoff immediately after burst – C1



CRJ Takeoff 50 s after burst – Region C2

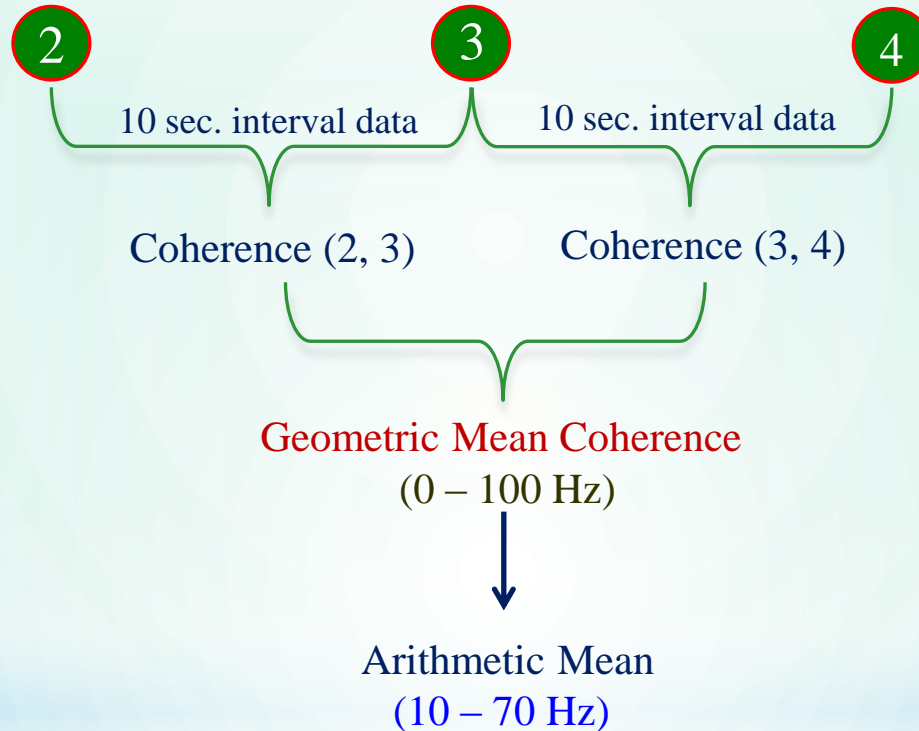


CRJ Takeoff 90 s after burst



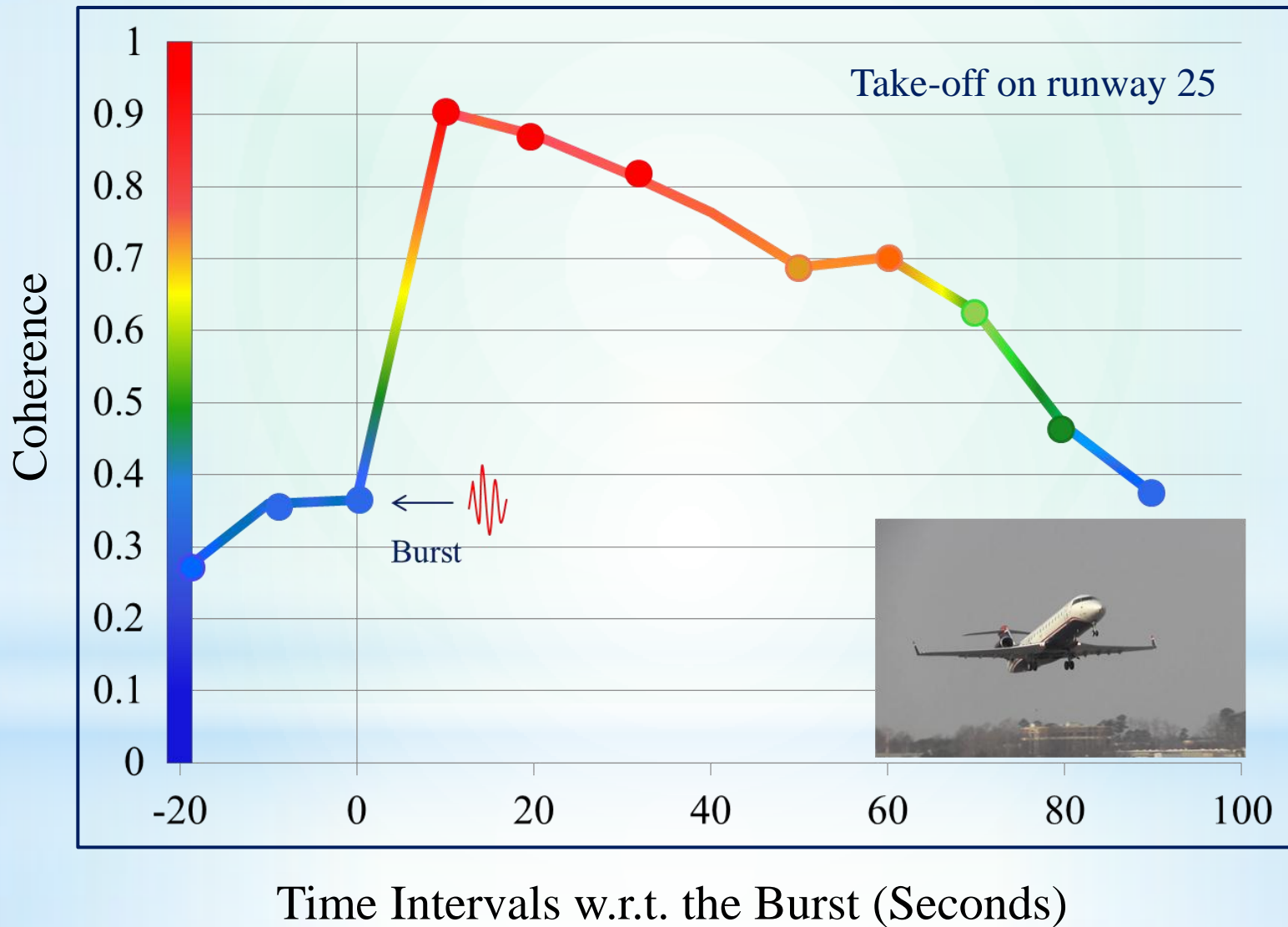
Data Processing

Infrasonic array installed along the runway

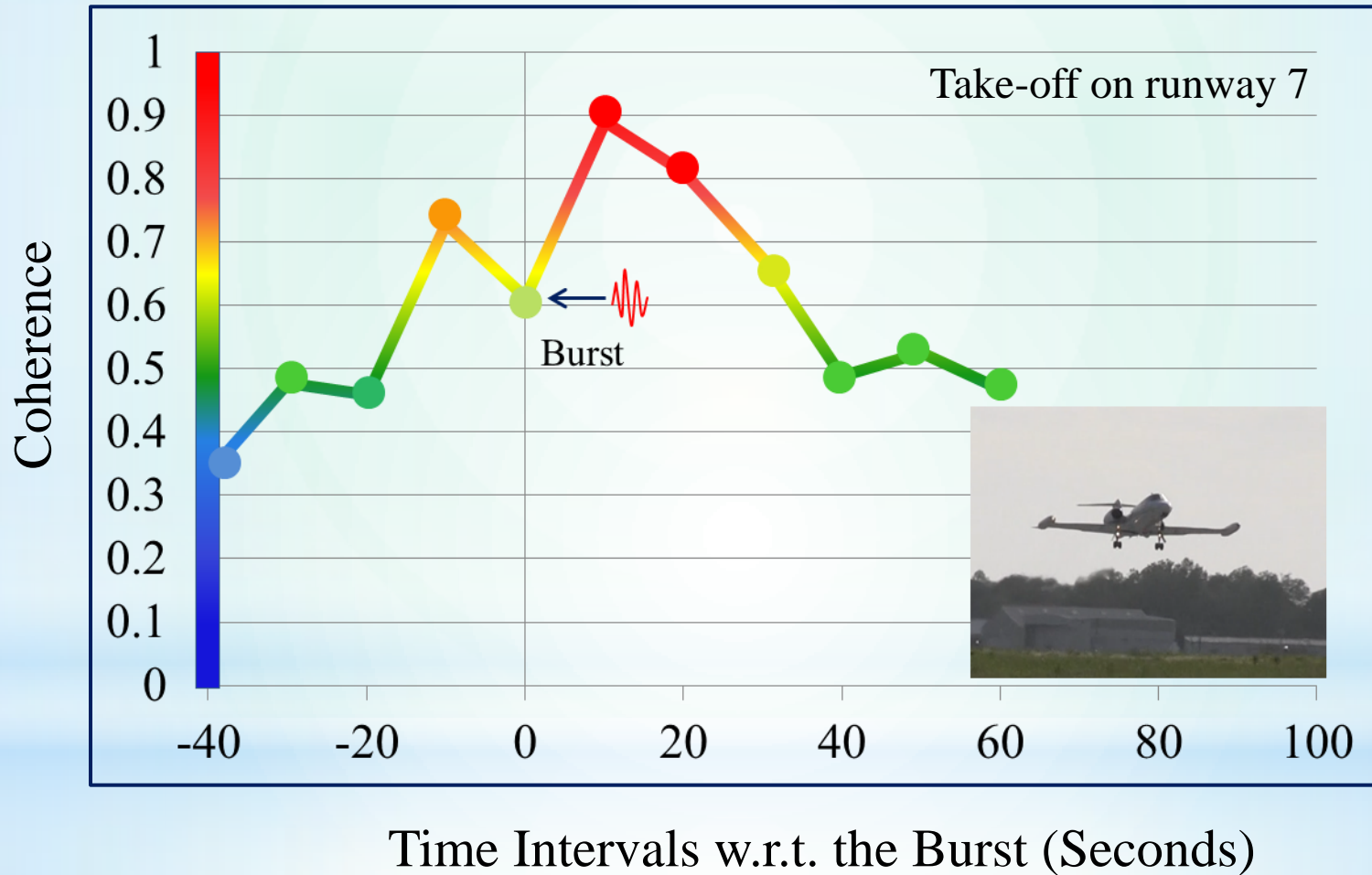


The arithmetic mean of each 10 second interval is used to calculate coherence time history. Then spectrogram is plotted to monitor the life span of wake vortices shed from each aircraft.

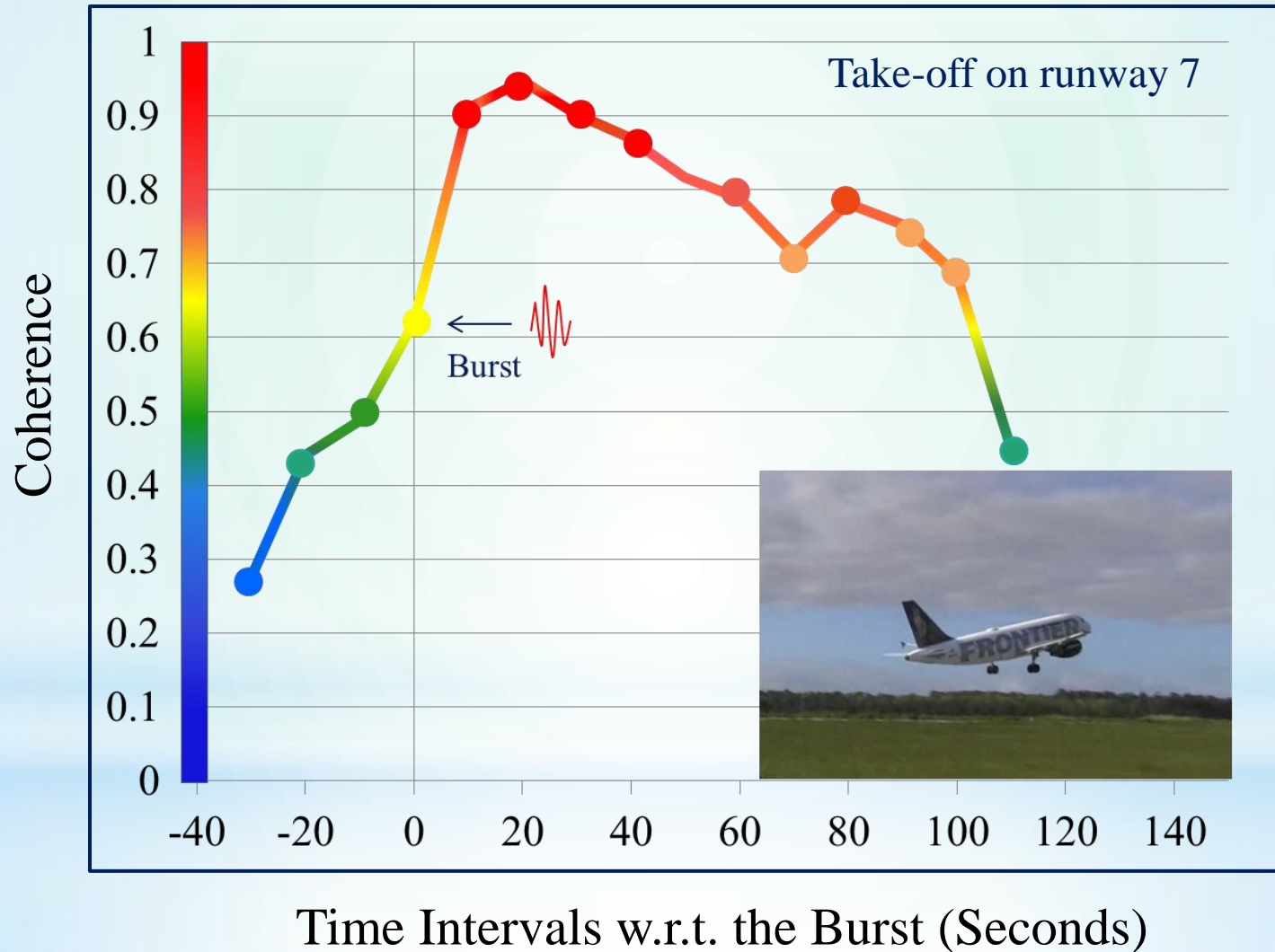
Coherence vs. Time (CRJ Takeoff)



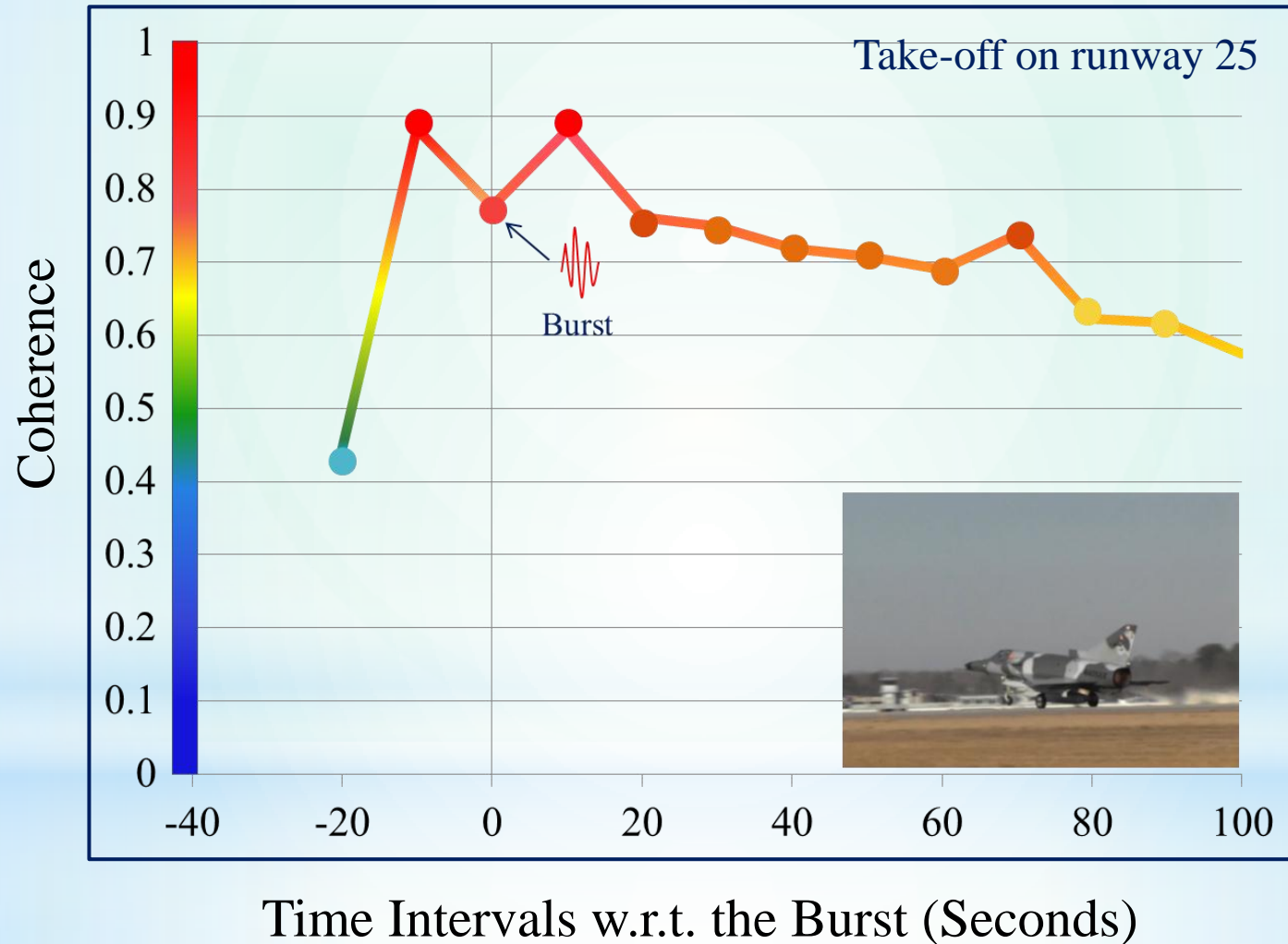
Coherence vs. Time (Corporate Takeoff)



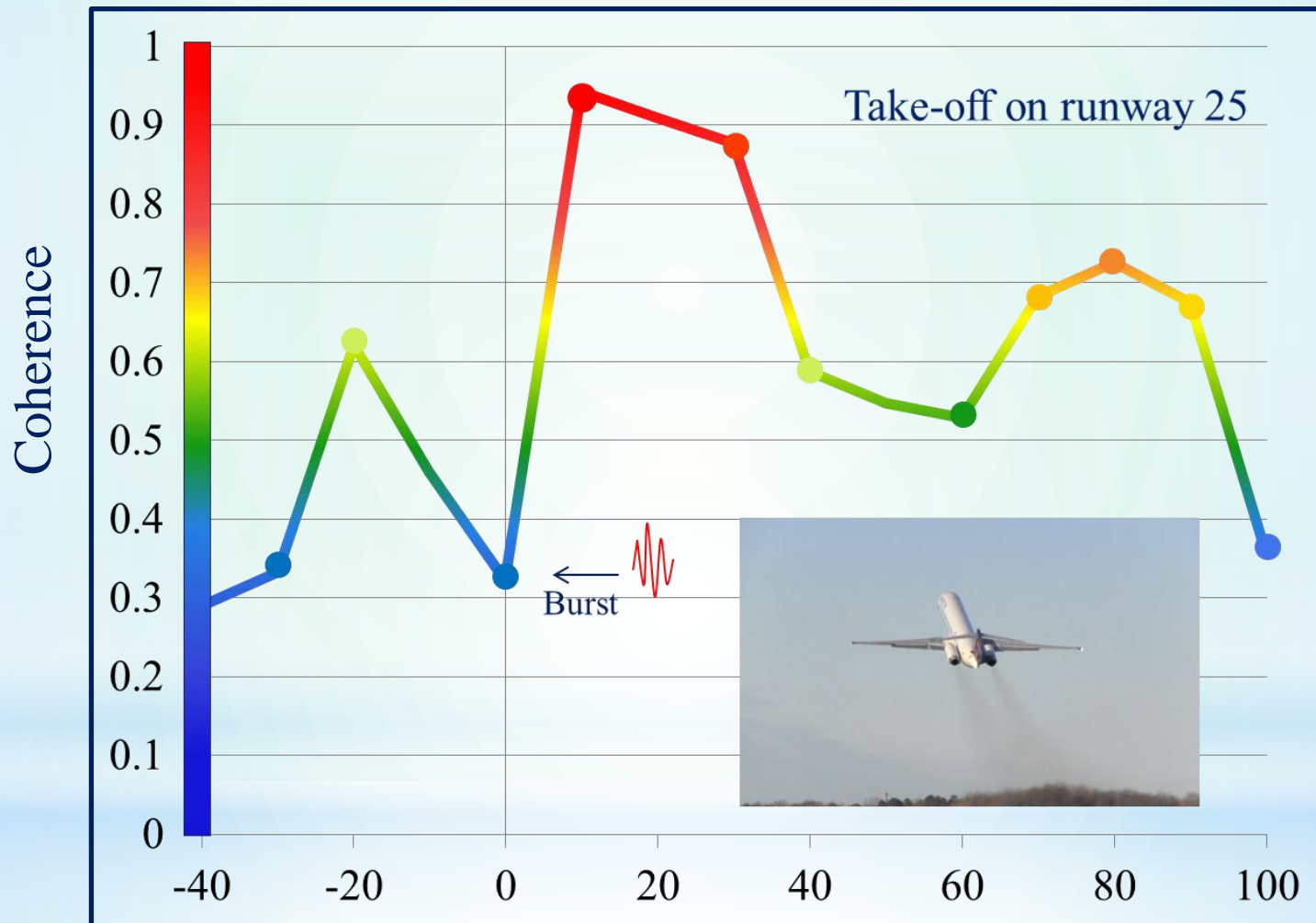
Coherence vs. Time (Airbus Takeoff)



Coherence vs. Time (Kfir Military Jet Takeoff)

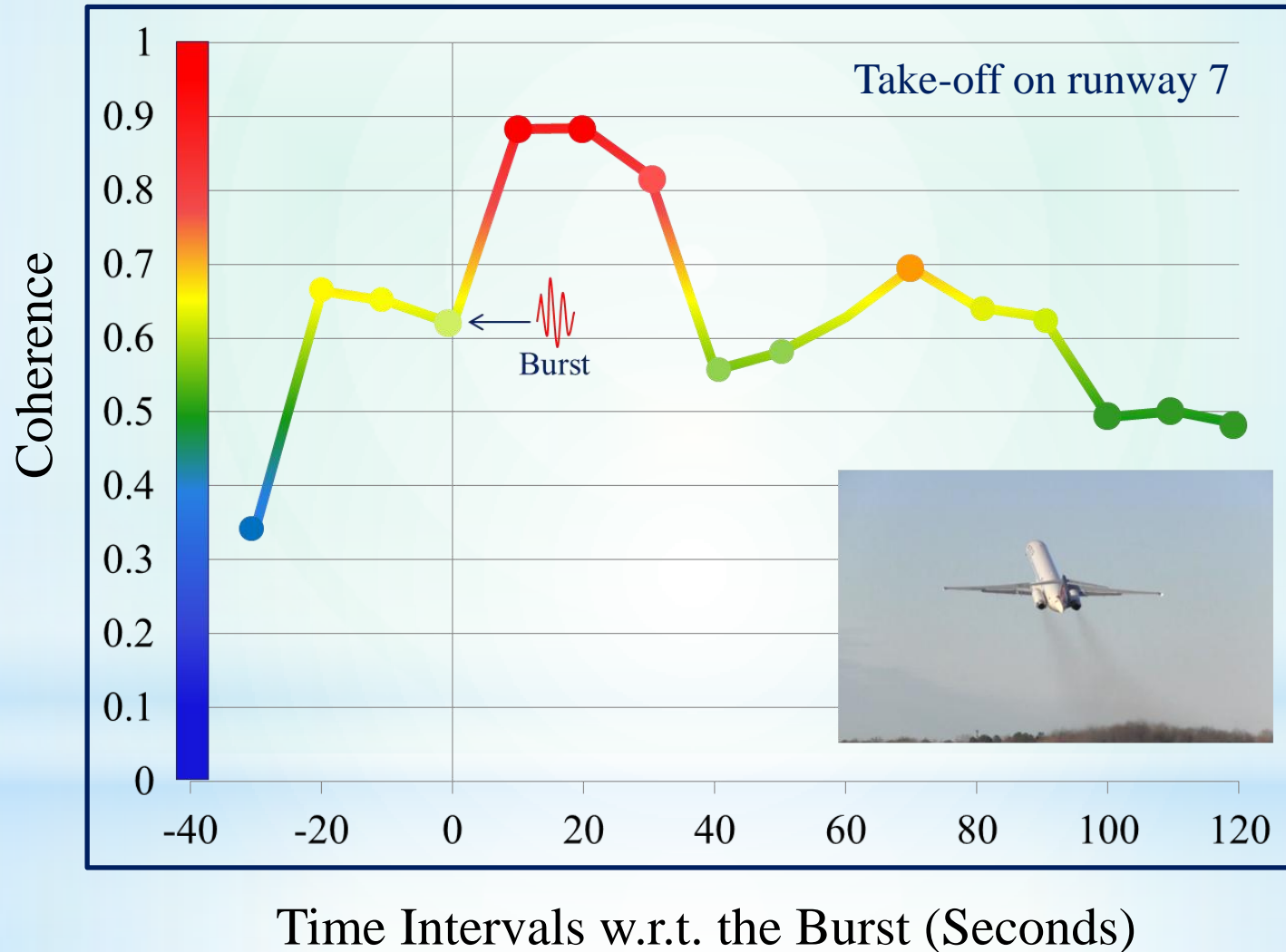


Coherence vs. Time (MD88 Takeoff)

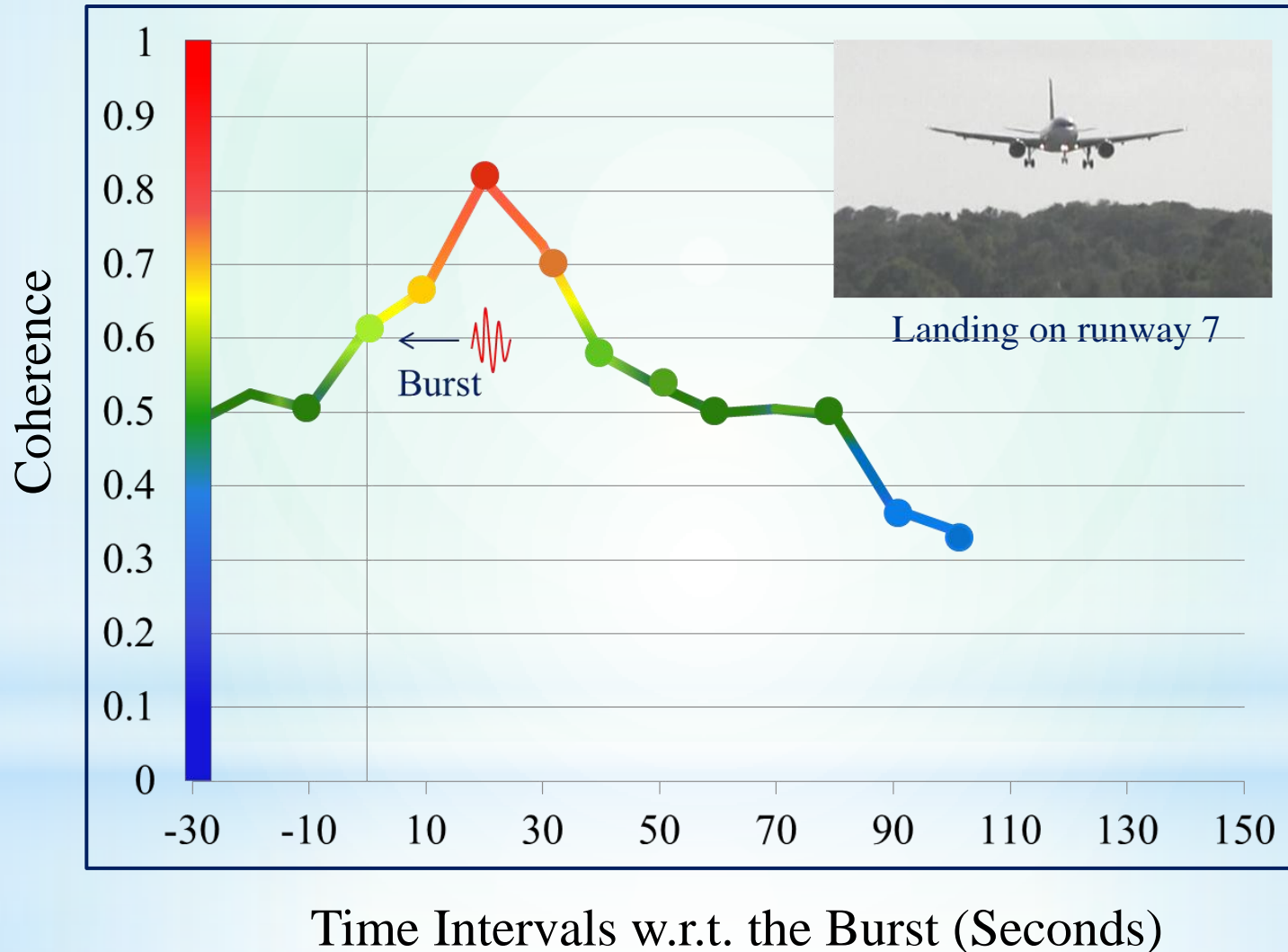


Time Intervals w.r.t. the Burst (Seconds)

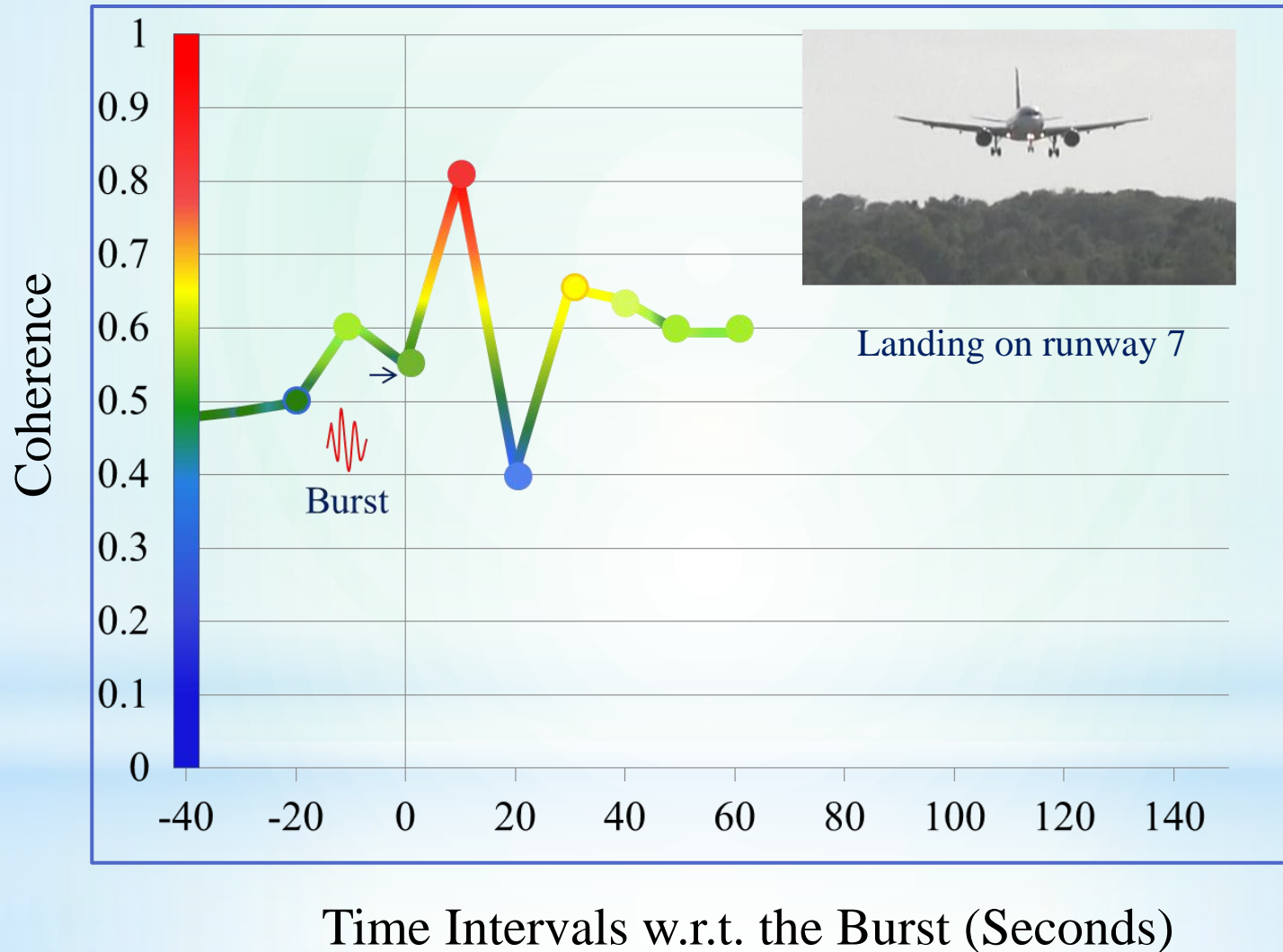
Coherence vs. Time (MD88 Takeoff)



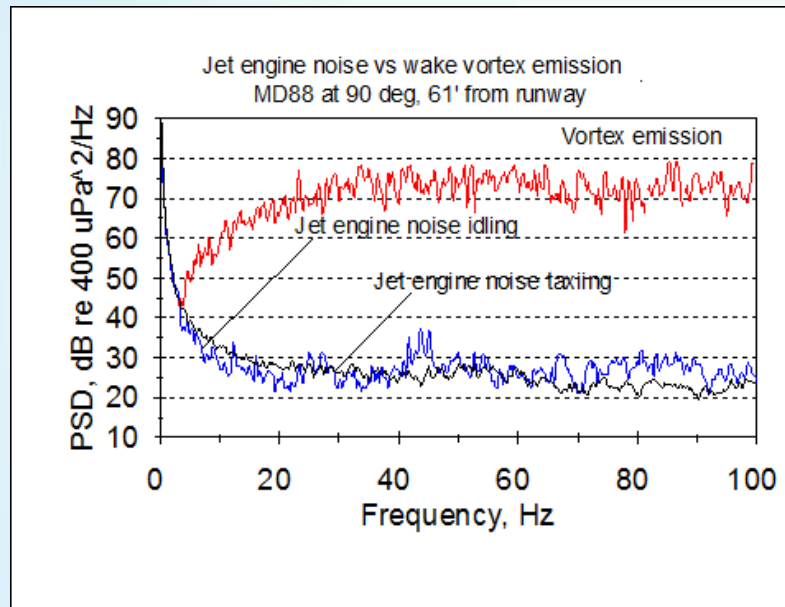
Coherence vs. Time (Airbus Landing)



Coherence vs. Time (Airbus Landing)



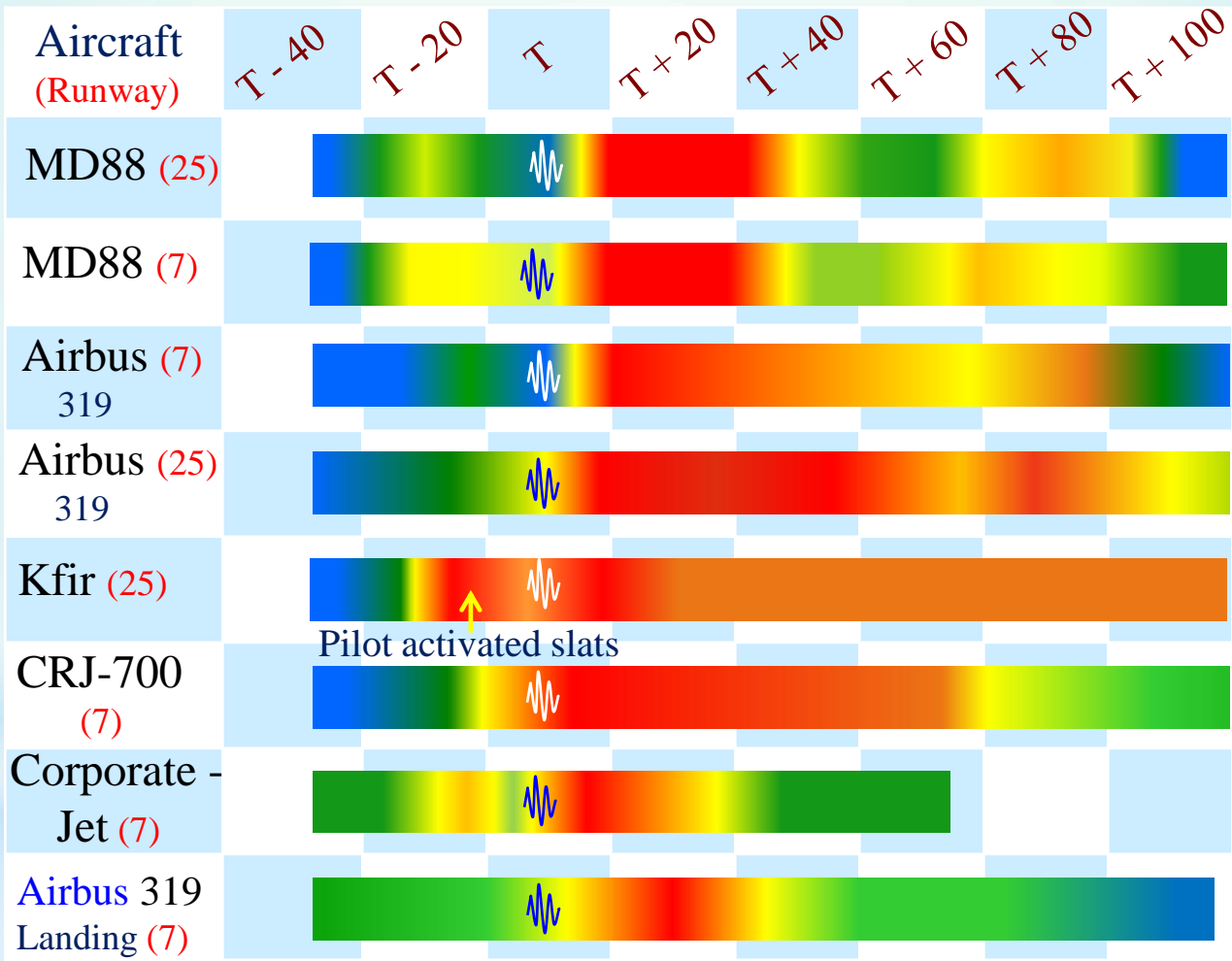
Jet Engine Noise vs. Tailing Wake Vortices



- Little difference between the emissions at idling and taxiing.
- The jet engine emissions for both the idling and taxiing cases lie well below the wake vortex emissions in the infrasonic region of the spectrum.

Summary Chart

(Coherence time histories)



Conclusions I



- Phased Array microphones were successful in determining that aircraft wakes make sound.
- Phased Array microphones are not suitable for recording low frequency data.
- Despite relatively pristine acoustic environment, aircraft flyover was 20 dB louder than wake.
- Using three infrasonic microphone array system along the runway our group successfully recorded infrasonic signature of wake vortices of each aircraft.

Conclusions II



- Wake vortex emission spectra are broad band.
- Cross-spectral coherence has proved an effective designator for tracking time history.
- The pattern of pressure burst, high coherence intervals, and diminishing coherence intervals was observed for all take-off and landing events without exception.
- The appearance of pressure bursts when aircraft pass microphones has never been reported before. They serve a reliable time stamp.