



Analysis of noise from reusable solid rocket motor (RSRM) firings

Kent L. Gee

Brigham Young University

Tracianne B. Neilsen

Brigham Young University

R. Jeremy Kenny

NASA Marshall Space Flight Center

Christopher M. Hobbs

Wyle Laboratories

Trevor W. Jerome

Brigham Young University

Michael M. James

Blue Ridge Research and Consulting

Introduction

- NASA's Space Launch Vehicle (SLS) program has chosen the Reusable Solid Rocket Motor V (RSRMV) as the booster system for initial flights.
- Lift off acoustics continue to be a consideration in overall vehicle vibroacoustic evaluations and launch pad modifications.
- Work started with the Ares program to understand solid rocket noise mechanisms is continuing through SLS program in conjunction with BYU / Blue Ridge Research Consulting.



NASA plans giant deep space rocket
The Space Launch System (SLS) – designed to carry astronauts to the moon, Mars and other destinations – will be the most powerful launcher ever built. The SLS will have a greater lift capacity than the Saturn V rocket which carried men to the Moon

U.S. LAUNCH SYSTEMS		
Saturn V 1967-73 Height 111m Lift capacity 118,000kg	Space Shuttle 1981-2011 56m 22,500kg	SLS First launch scheduled by end of 2017 122m 130,000kg Project cost \$18bn by 2017

Rocket
Based on space shuttle's liquid hydrogen and liquid oxygen engines and fuel tanks, coupled initially with upgraded solid-fuel shuttle boosters

Main stage
Five RS-25D/E engine

Solid boosters

Crew vehicle
Upper stage
J-2X engine

MULTI-PURPOSE CREW VEHICLE
Launch abort system
Propels crew module to safety in case of emergency early in flight

Crew module
Carries main rocket engine, solar panels, and provides oxygen to astronauts

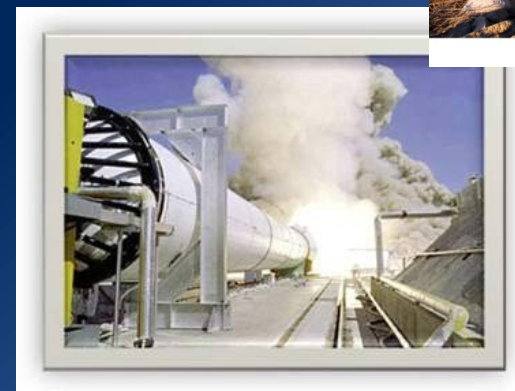
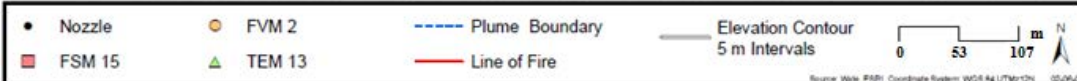
Spacecraft adapter
Attaches vehicle to booster

Crew vehicle: Similar to Apollo module, can carry four astronauts

Source: NASA Picture: NASA © GRAPHIC NEWS

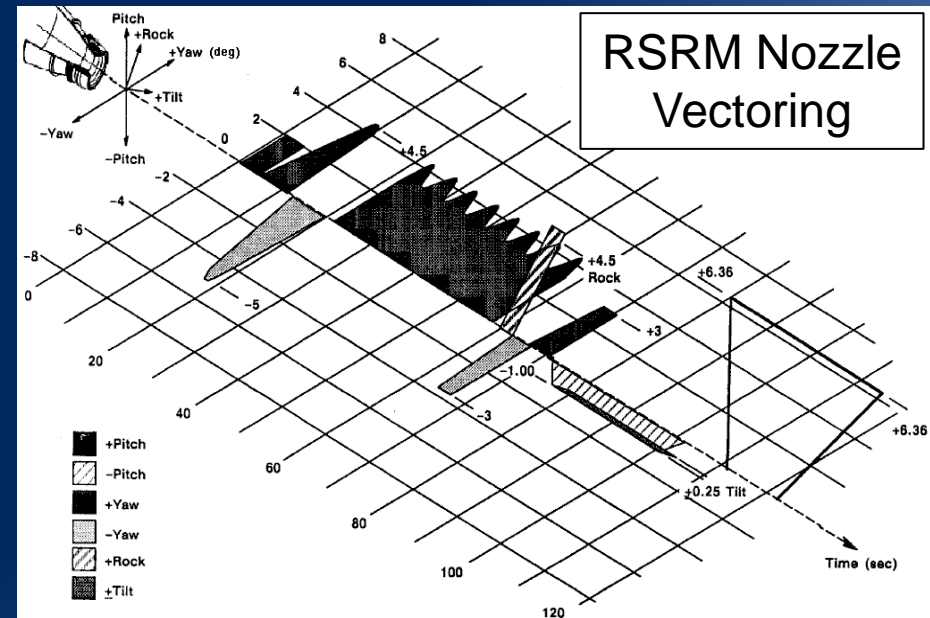
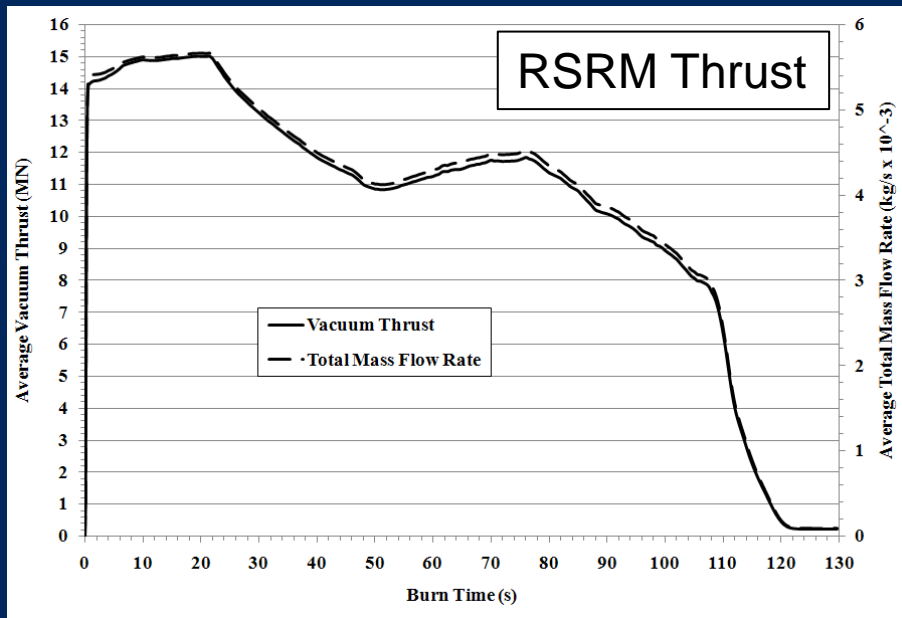
RSRM Acoustic Data Background (1)

- From 2007 – 2008, NASA and Wyle Labs collected free-field acoustic data from three RSRM static firings at over 20 locations.

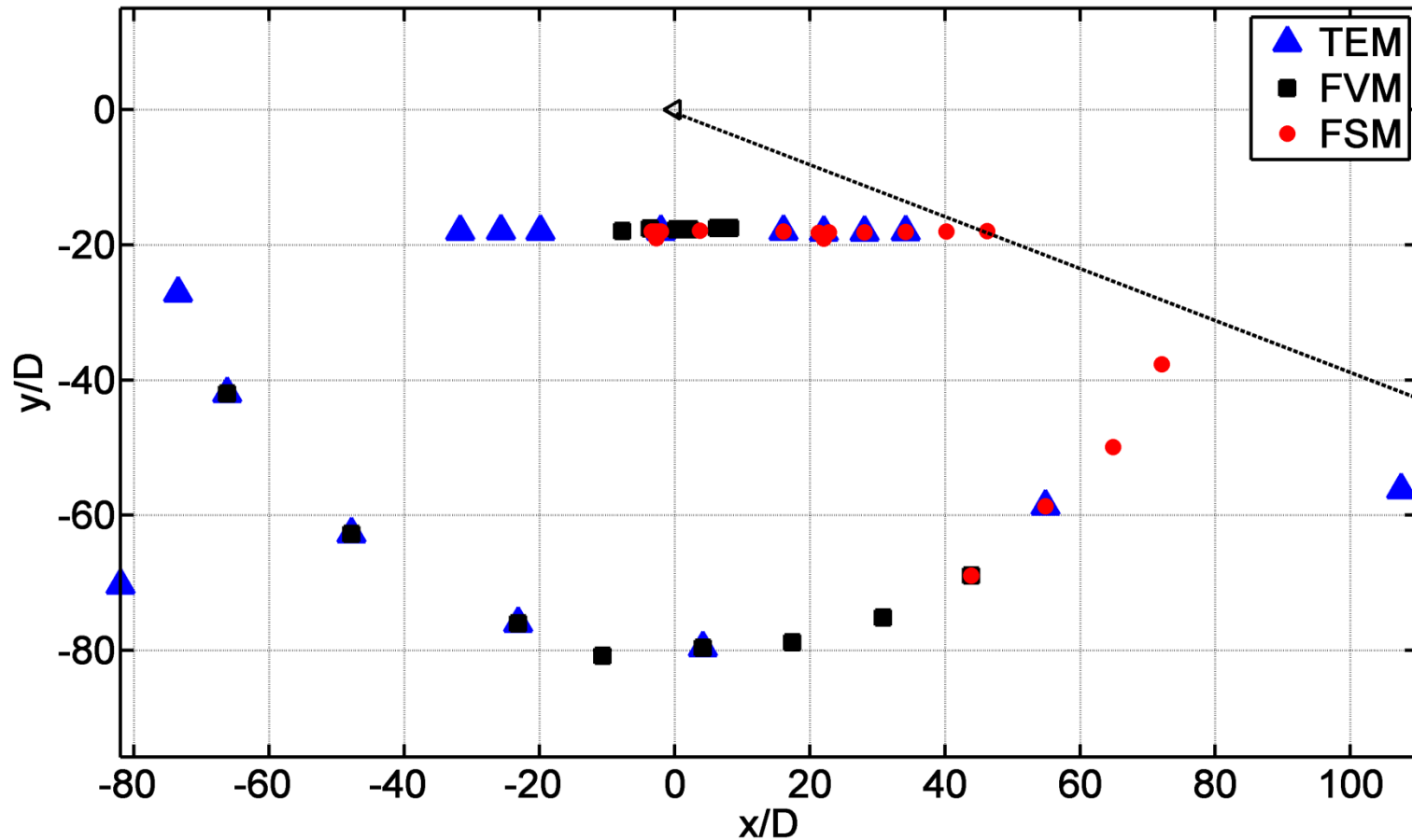


RSRM Acoustic Data Background (2)

- 1/4" microphones for all locations (B&K, GRAS)
- 48,000 and 96,000 sps collection rate
- Detail documented in AIAA 2009 - 3161

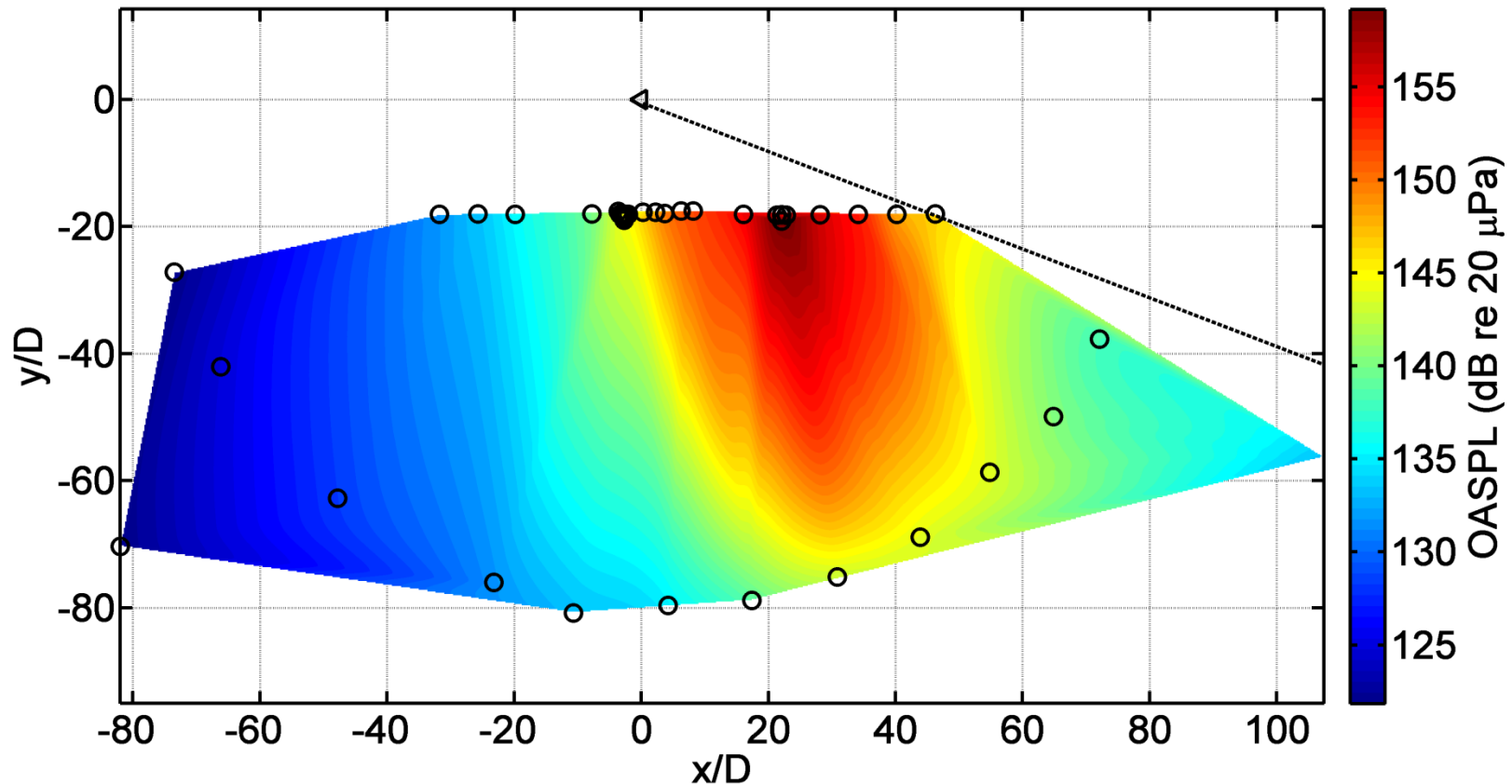


Combined Mic Locations



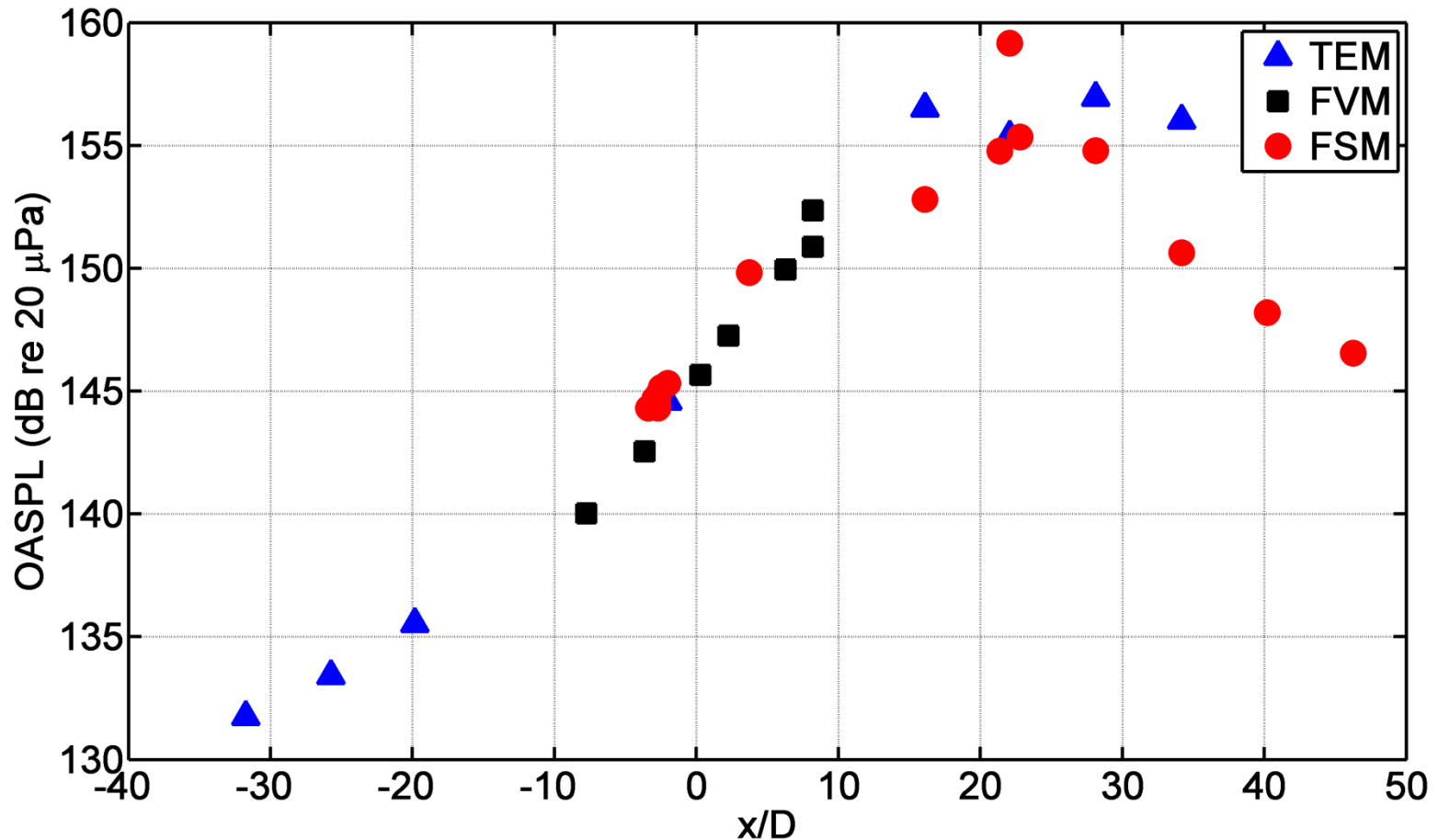
Combined OASPL

- Spatial data taken from the 50-60 s range for all three firings. Bilinear interpolation carried out using MATLAB.



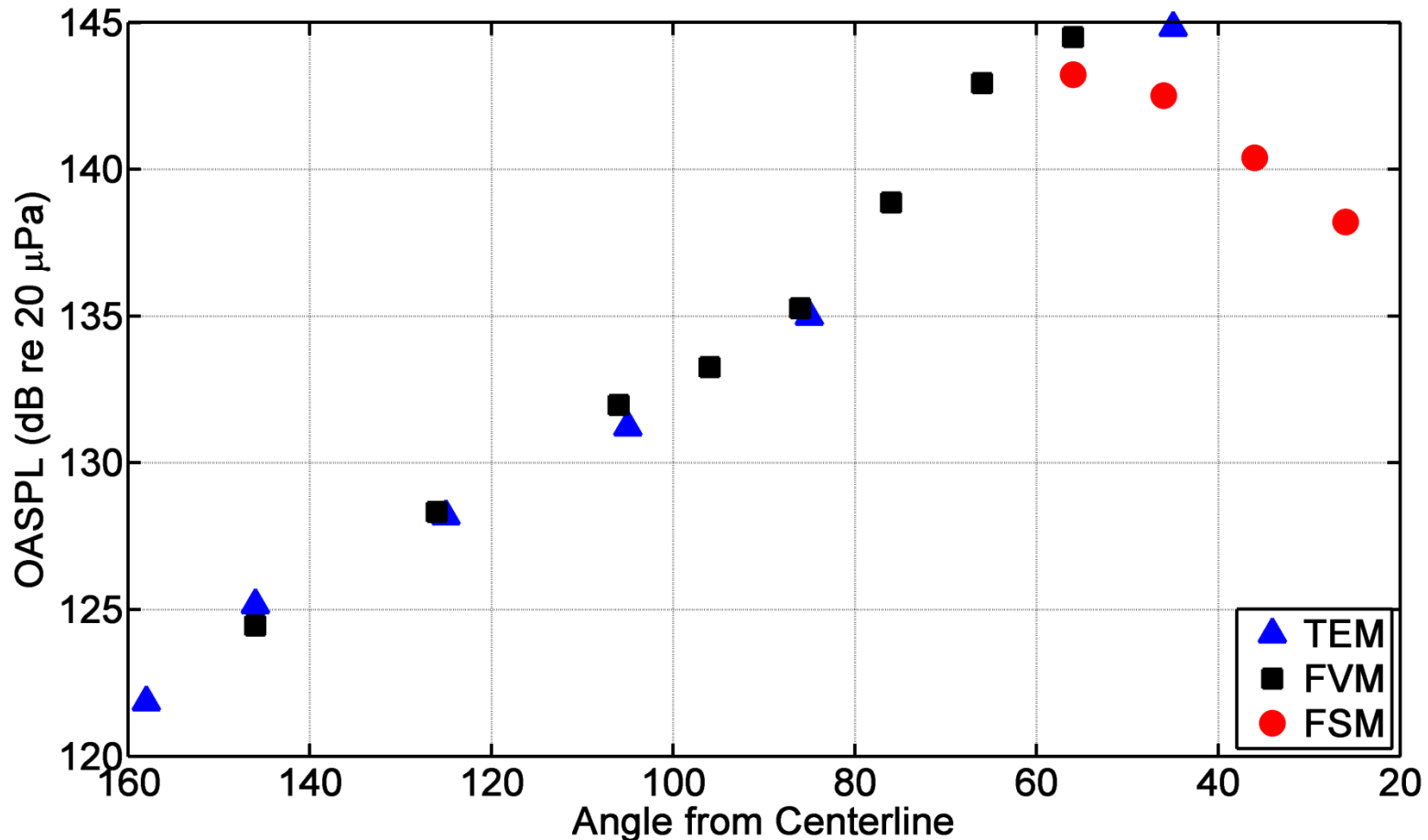
18 D OASPL

- Maximum OASPL region ~ 22 D, extending from 10-35 D.

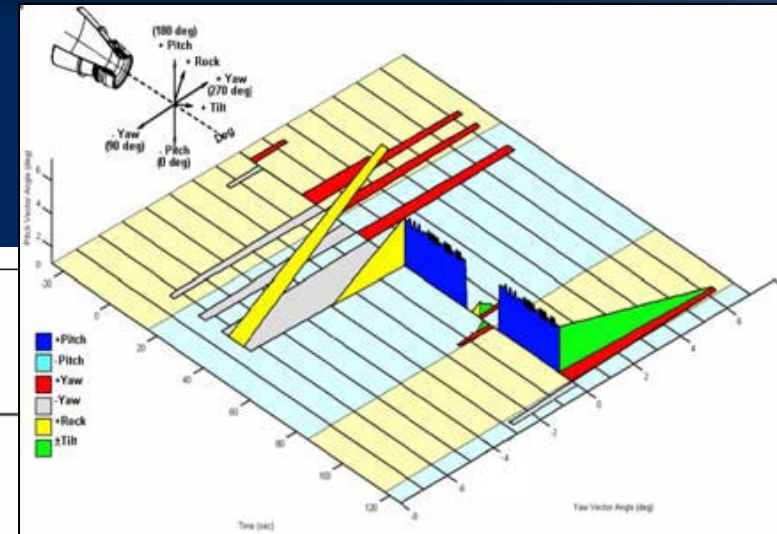
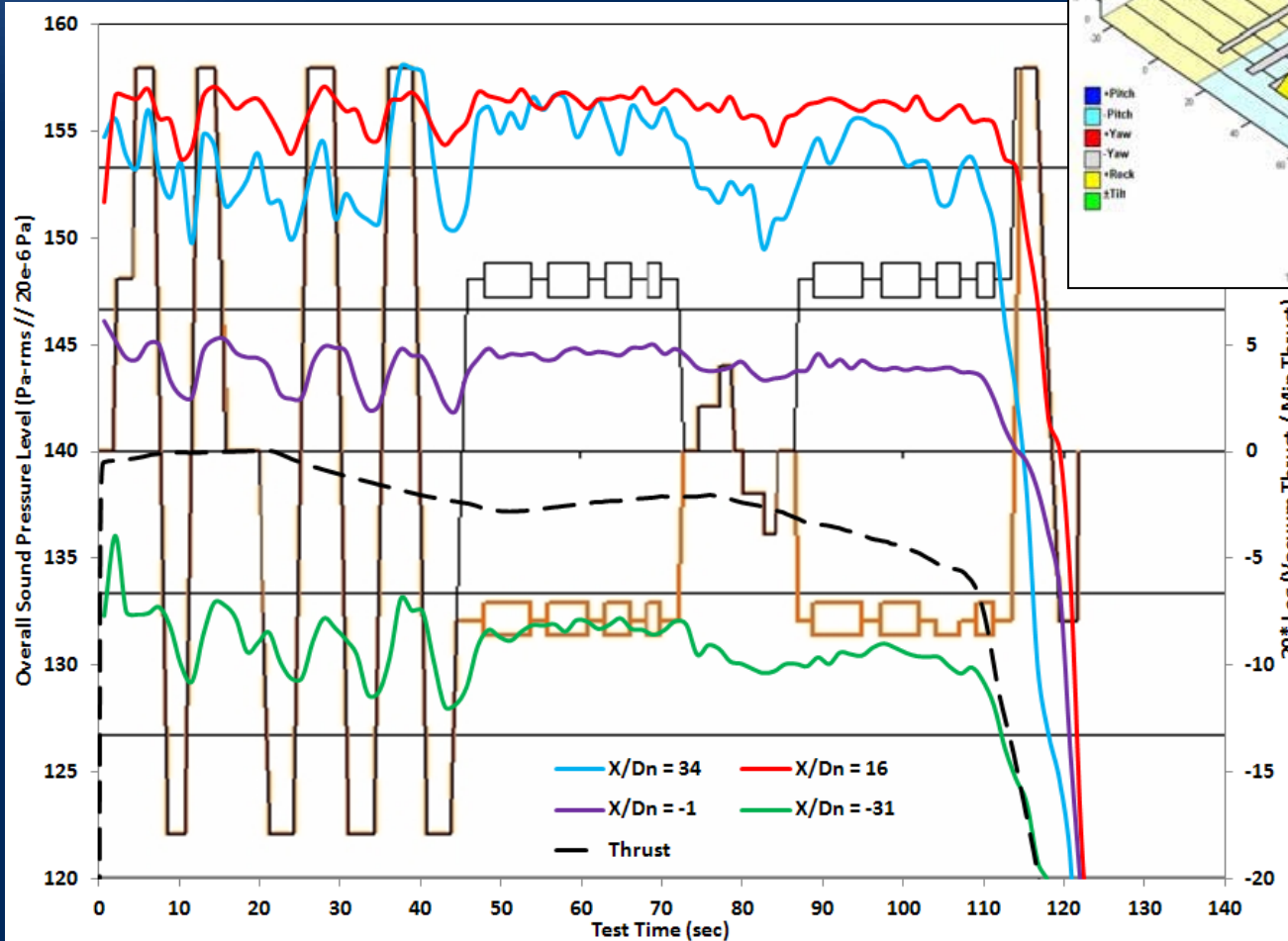


80 D Arc OASPL

- Maximum radiation in the 50-60° direction. Is only “directivity” if in the geometric far field. (?)

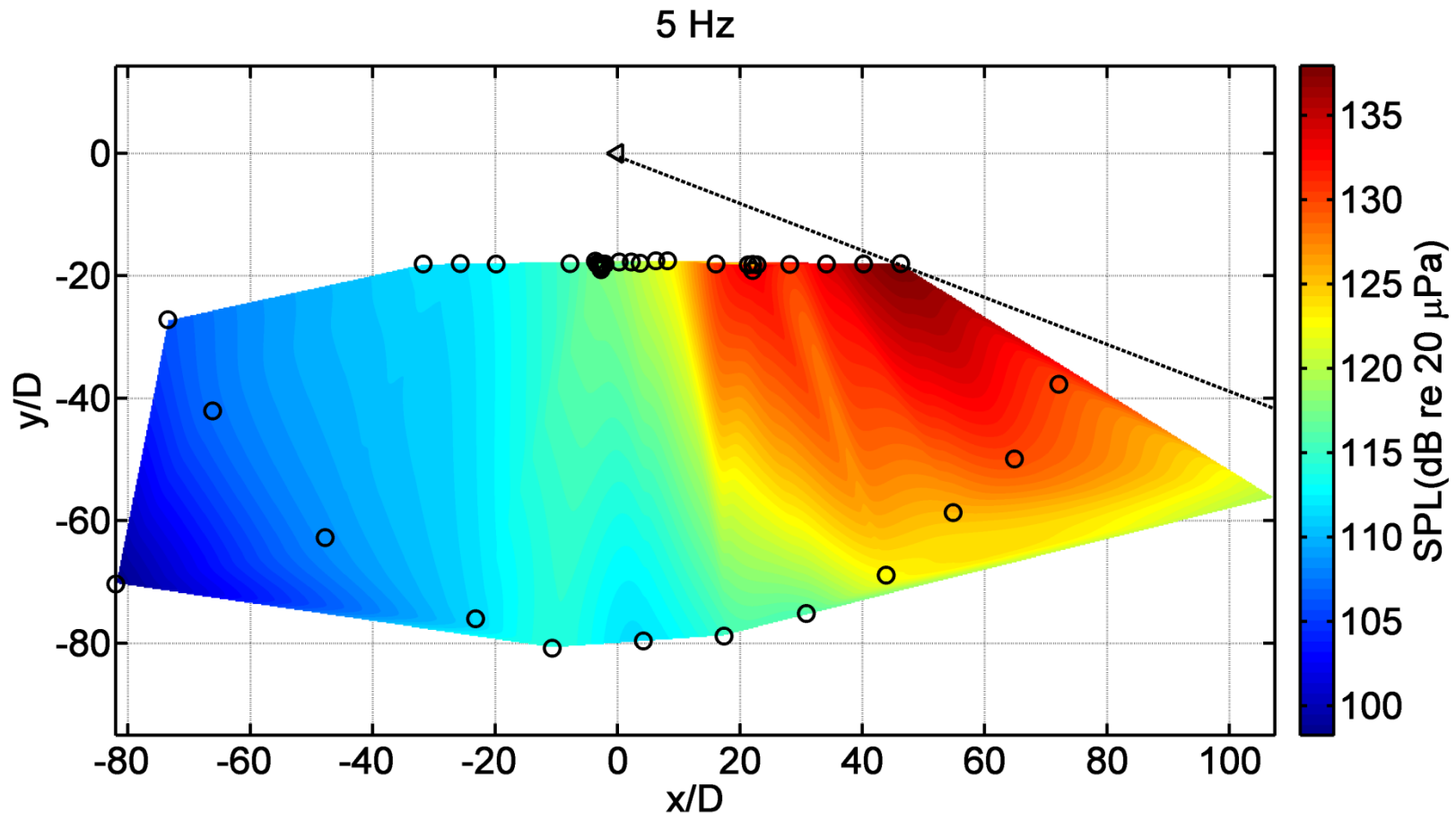


Running OASPL – TEM13 Firing

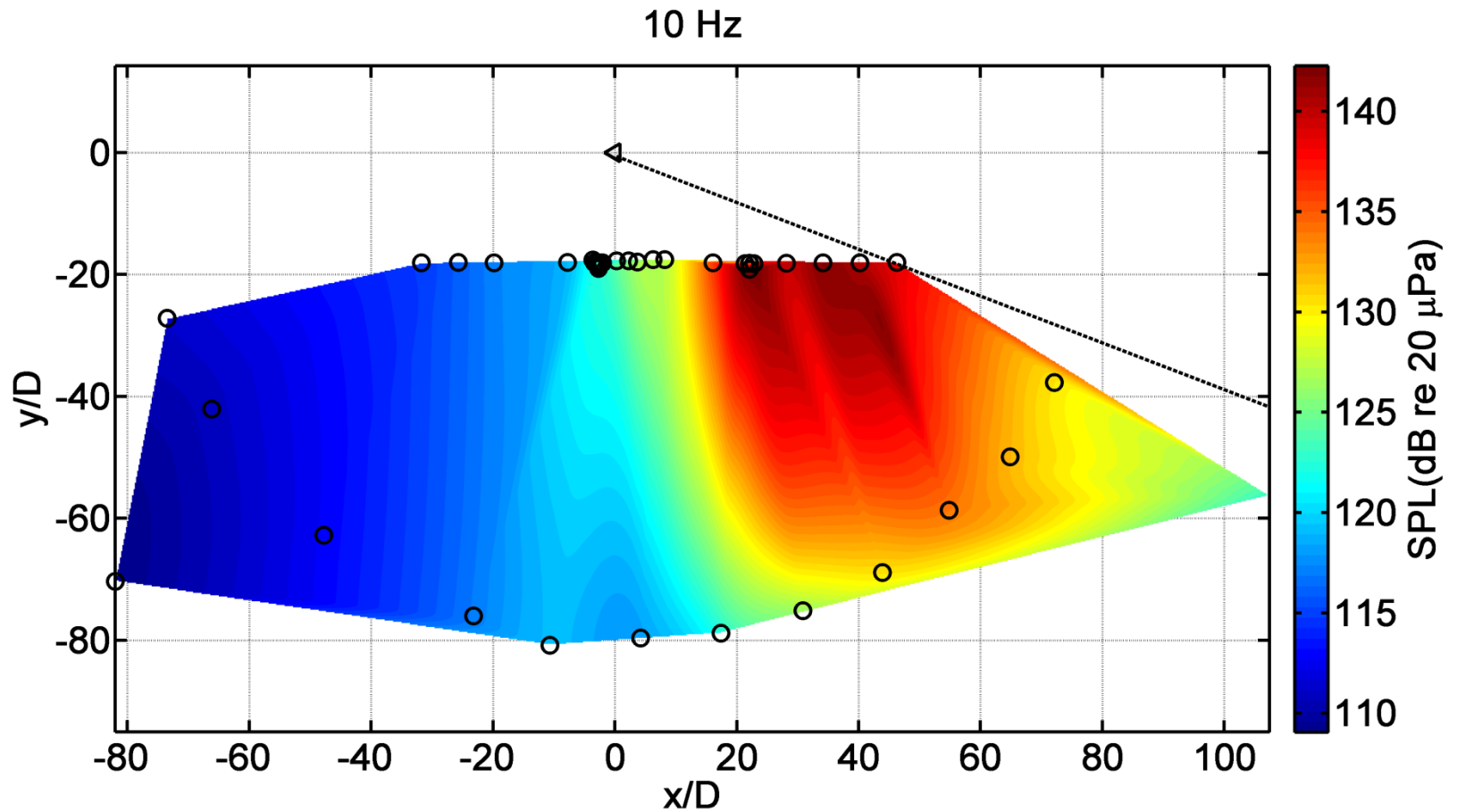


Band Pressure Levels

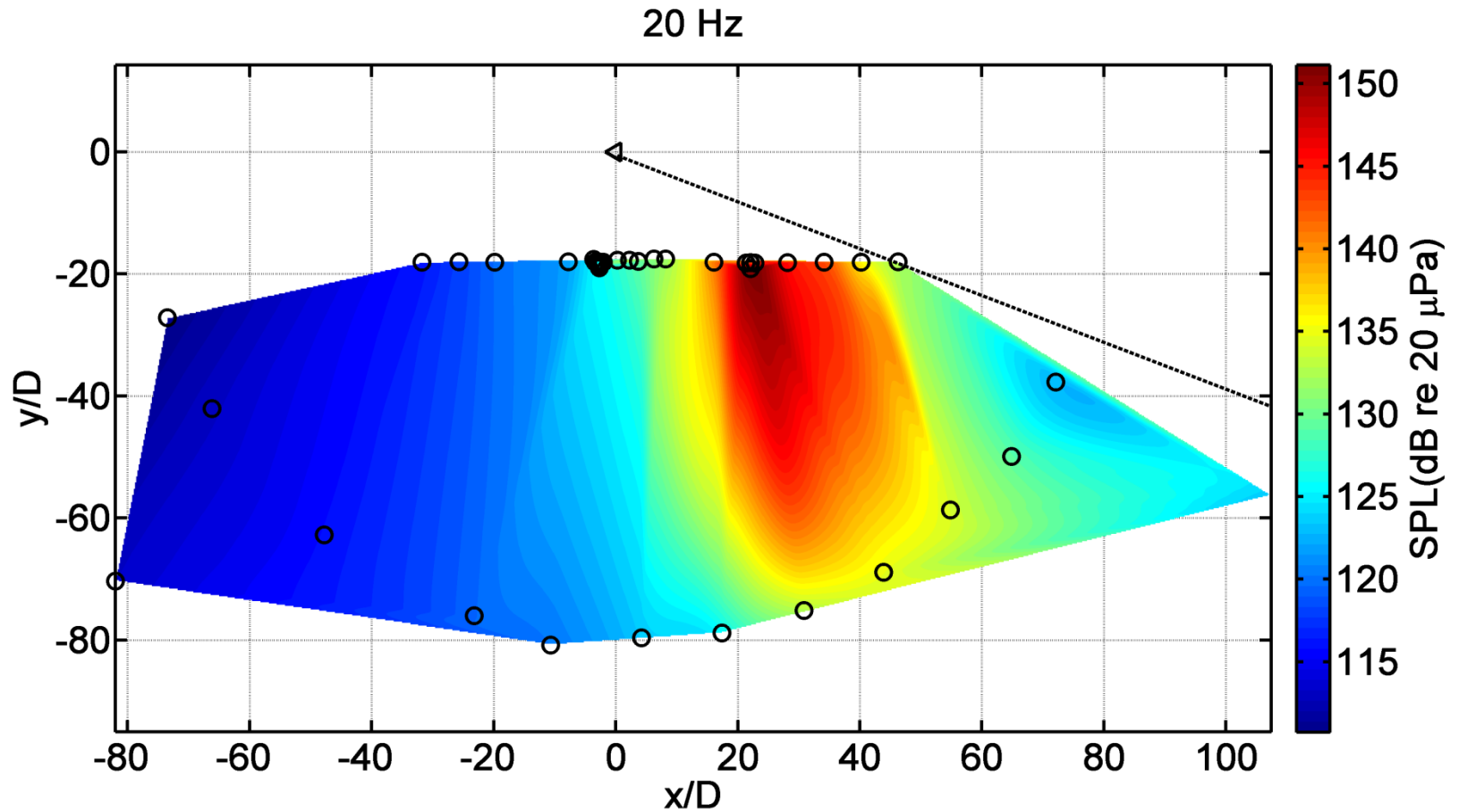
- One-third octave band plots reveal typical shift in max location/directionality but also curious behavior at high frequencies and the far aft angles.



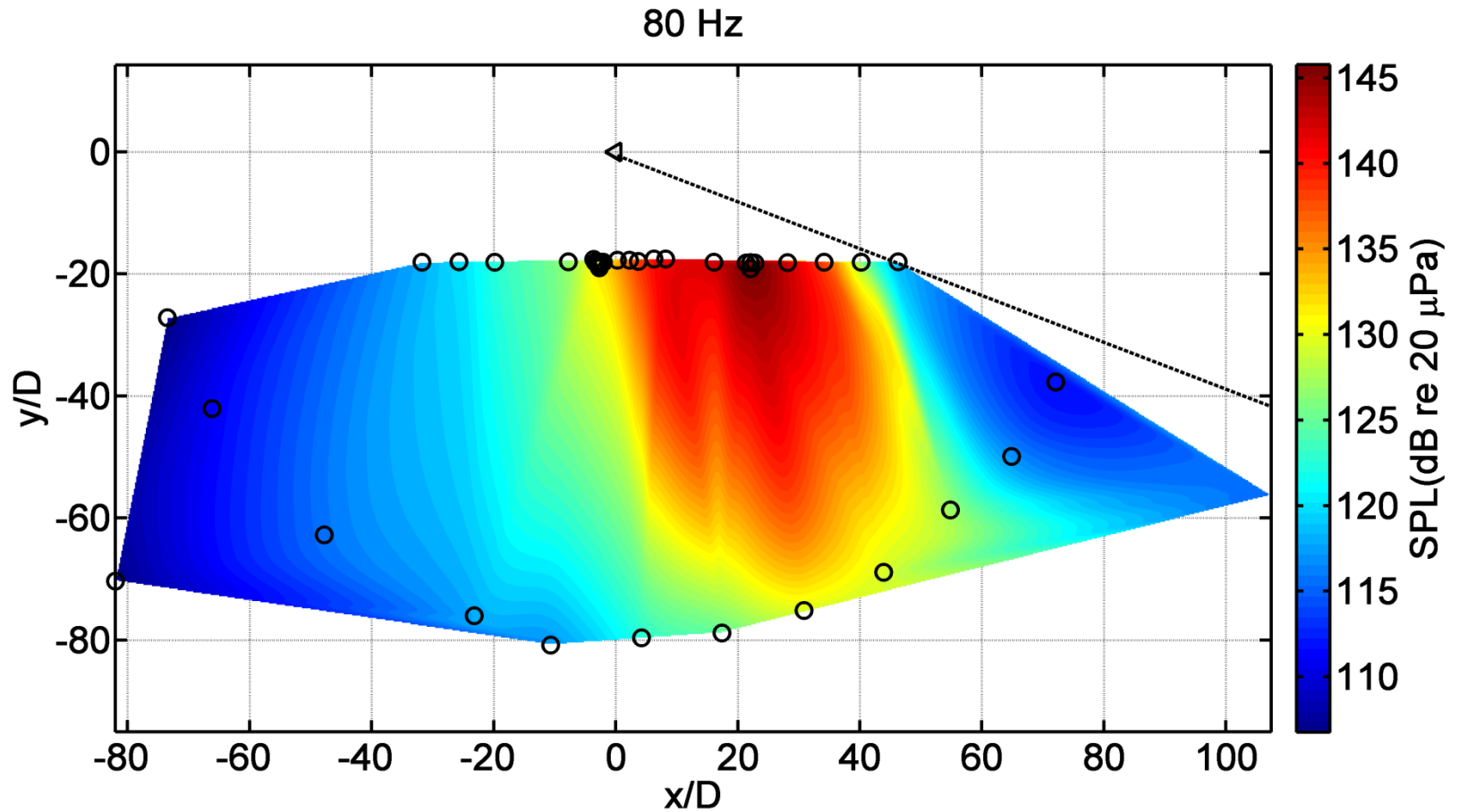
Band Pressure Levels



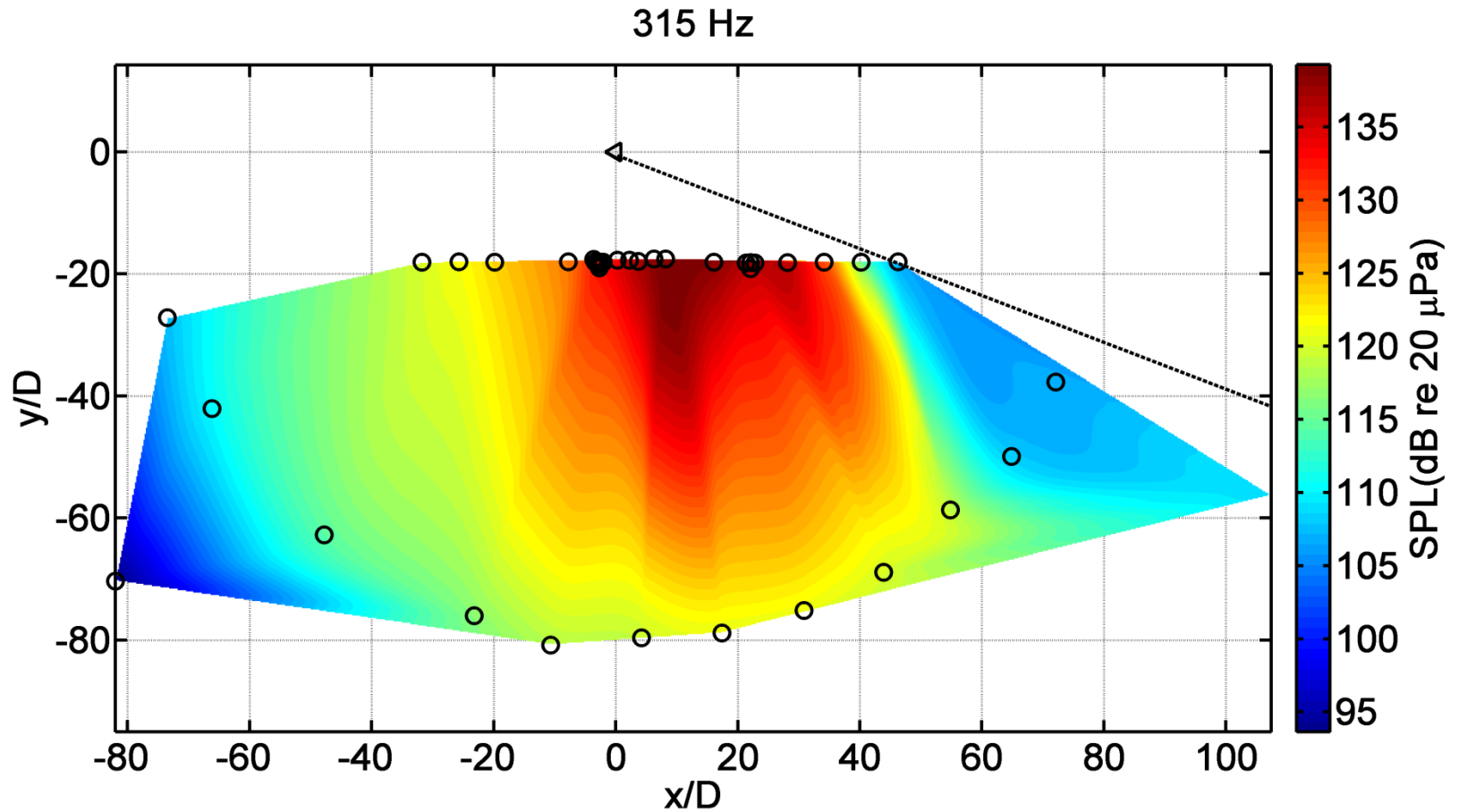
Band Pressure Levels



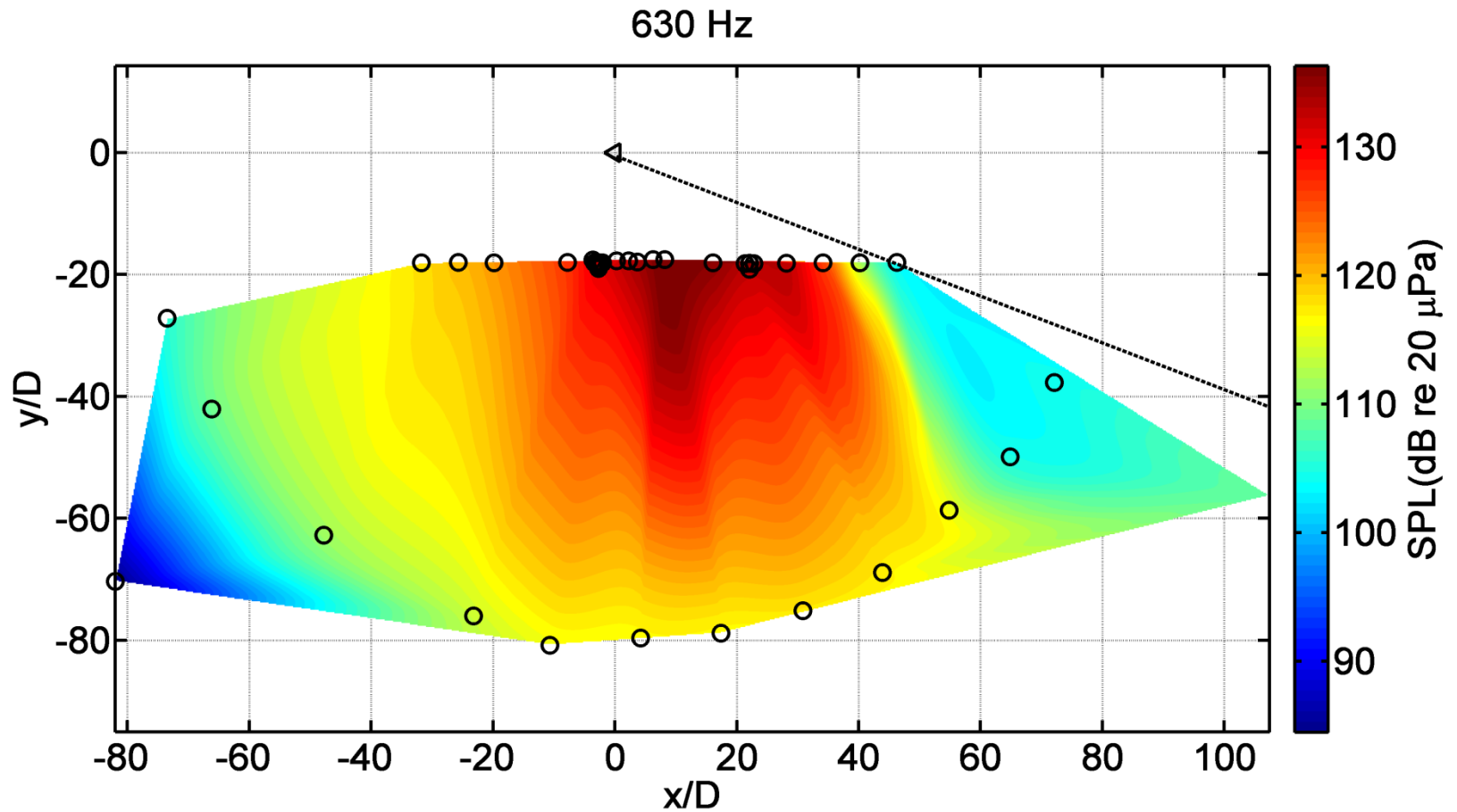
Band Pressure Levels



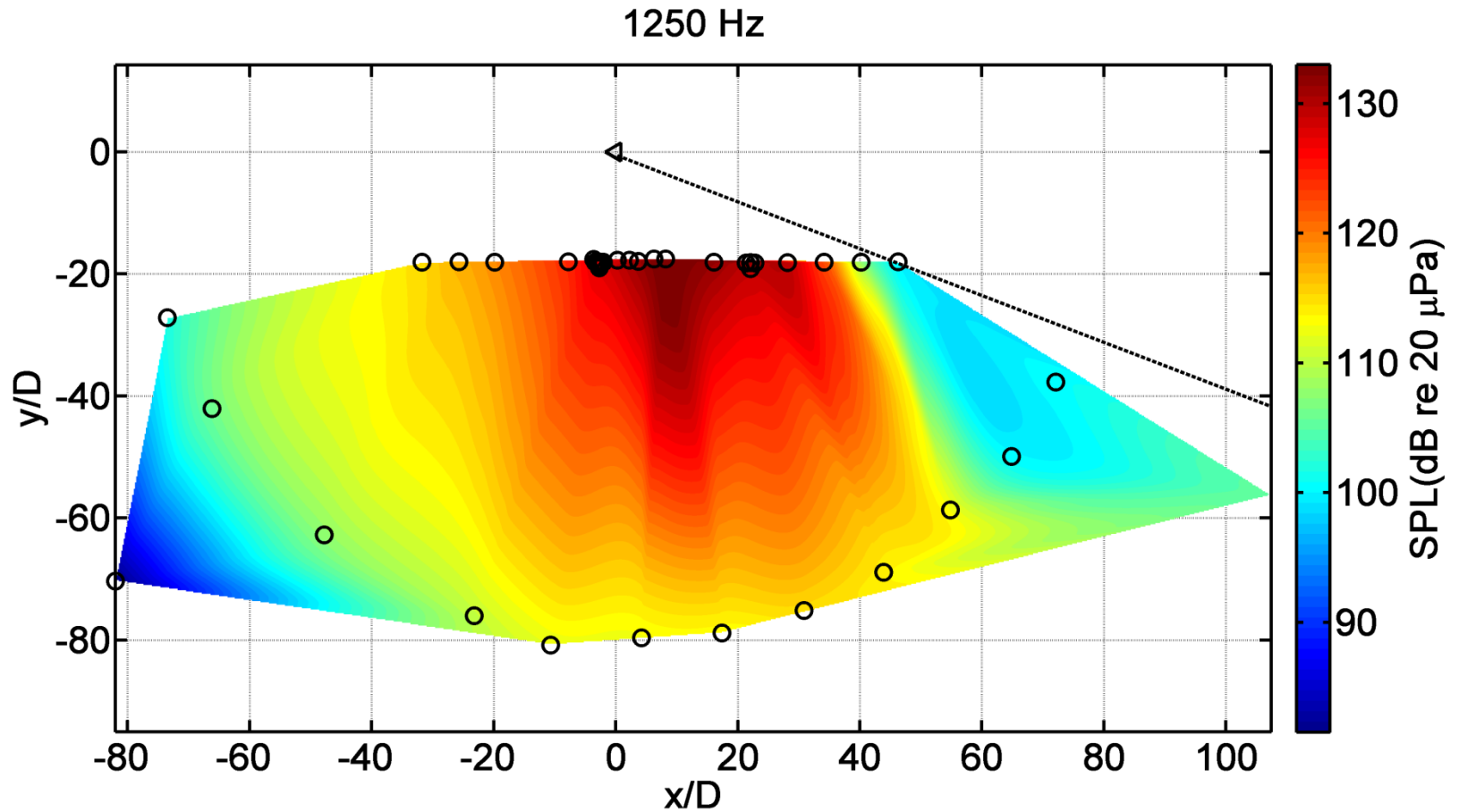
Band Pressure Levels



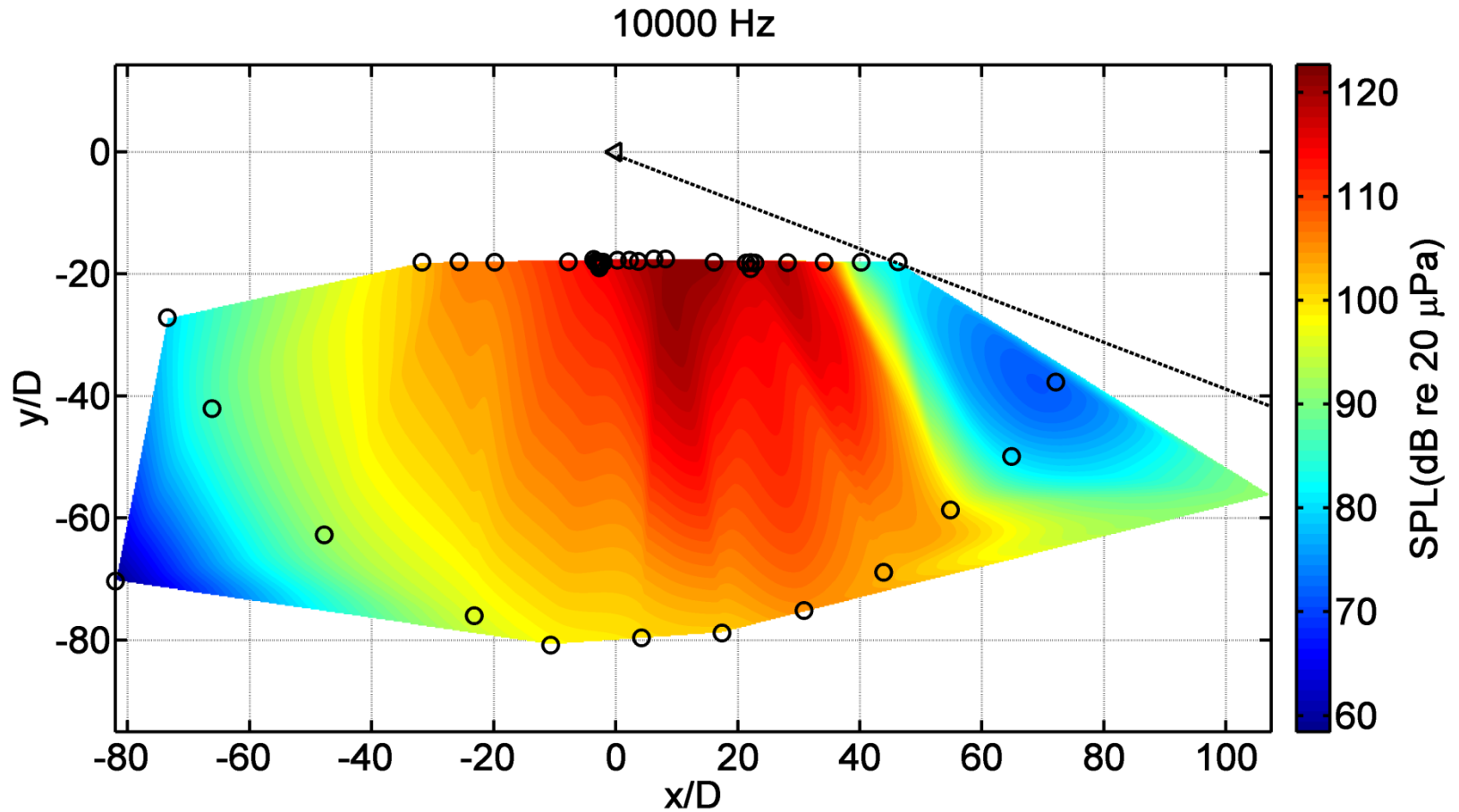
Band Pressure Levels



Band Pressure Levels

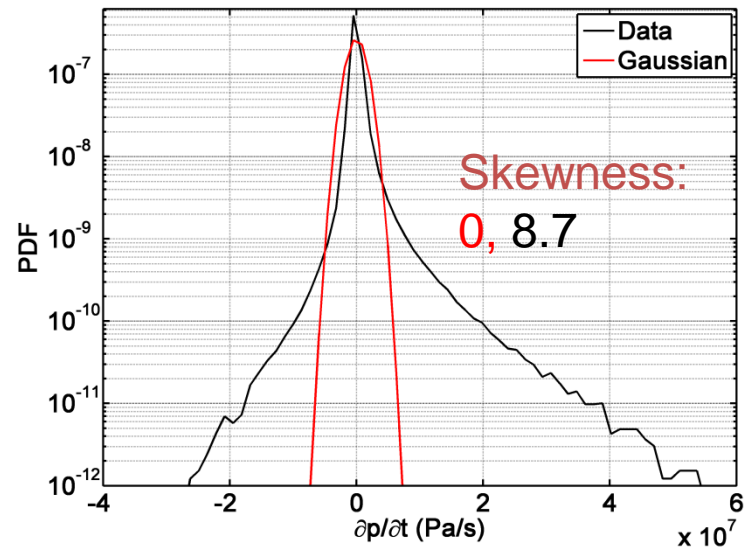
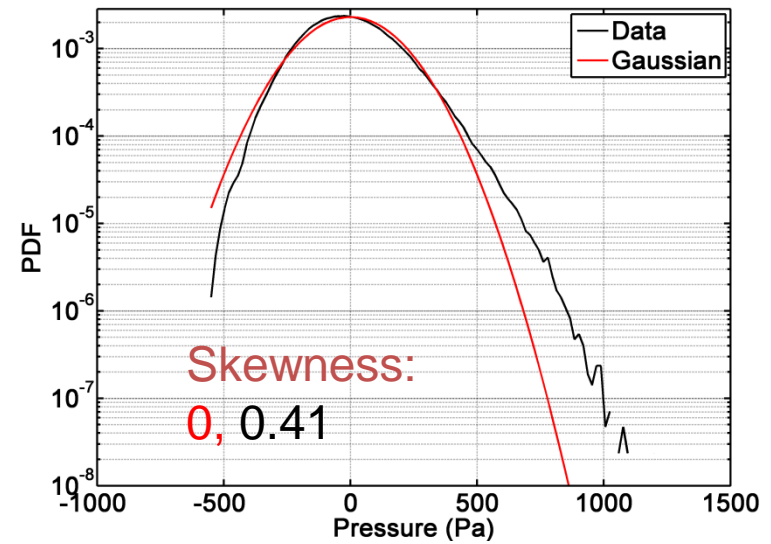
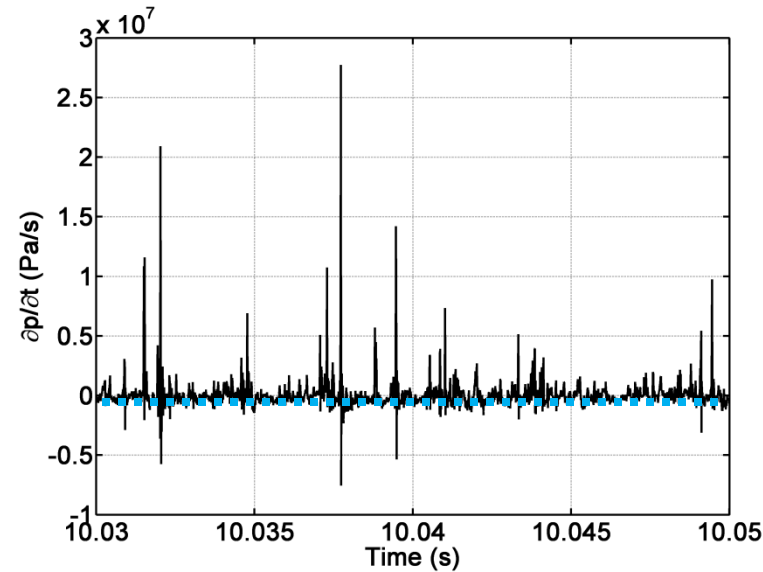
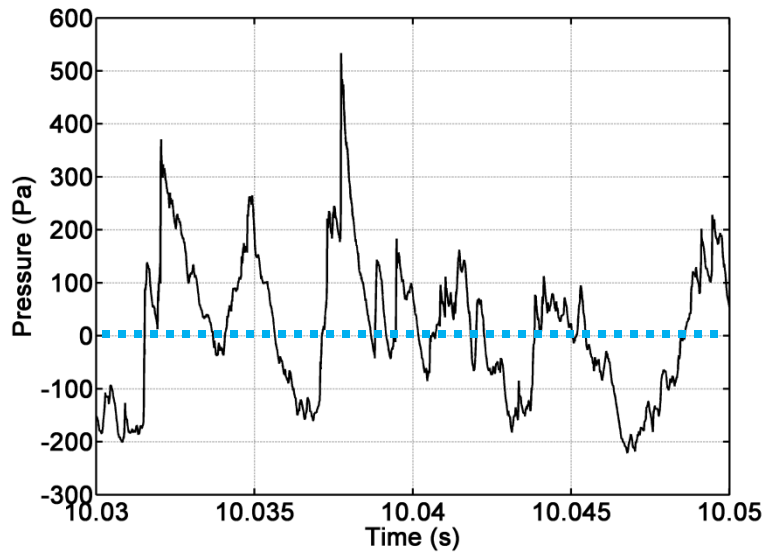


Band Pressure Levels



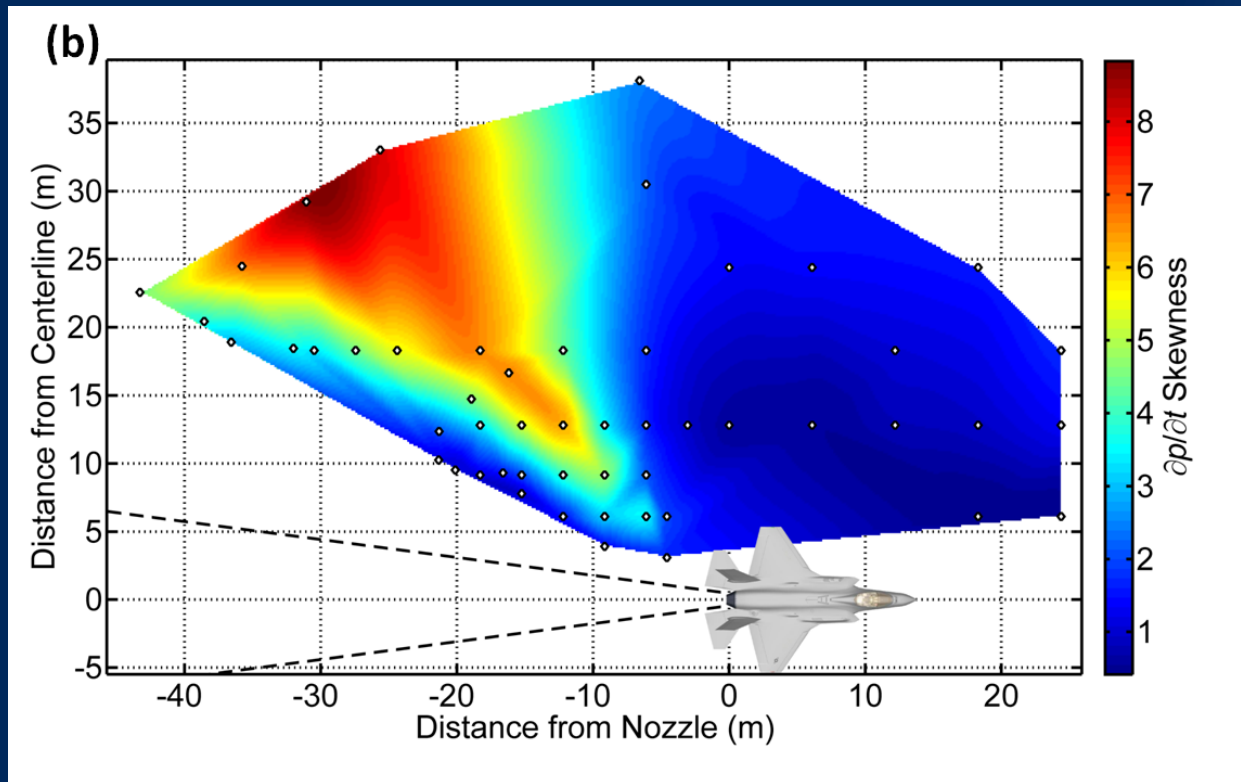
- Skewness
 - the normalized third-central moment of the probability density function
 - Measure of the “asymmetry” of the distribution
- Positive waveform skewness is a feature of high-amplitude noise radiated from supersonic jets and rockets. Its cause is not fully known
- Skewness of the waveform derivative has been used as an indicator of relative shock strength and extreme non-Gaussian behavior.

F-35 MIL Power Example



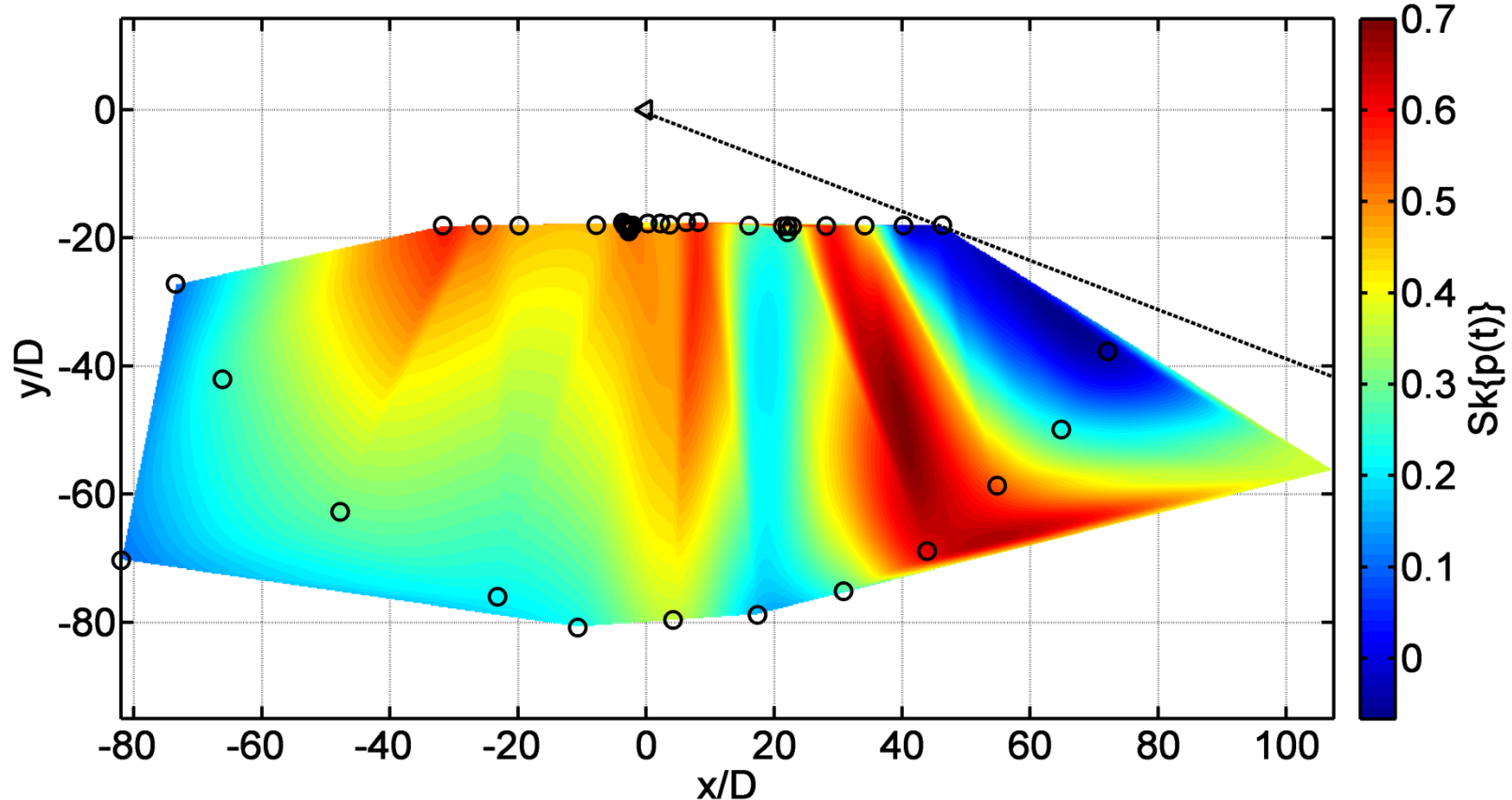
F-35 Comparison

- Also growth in derivative skewness, but much lower values at comparable scaled distances



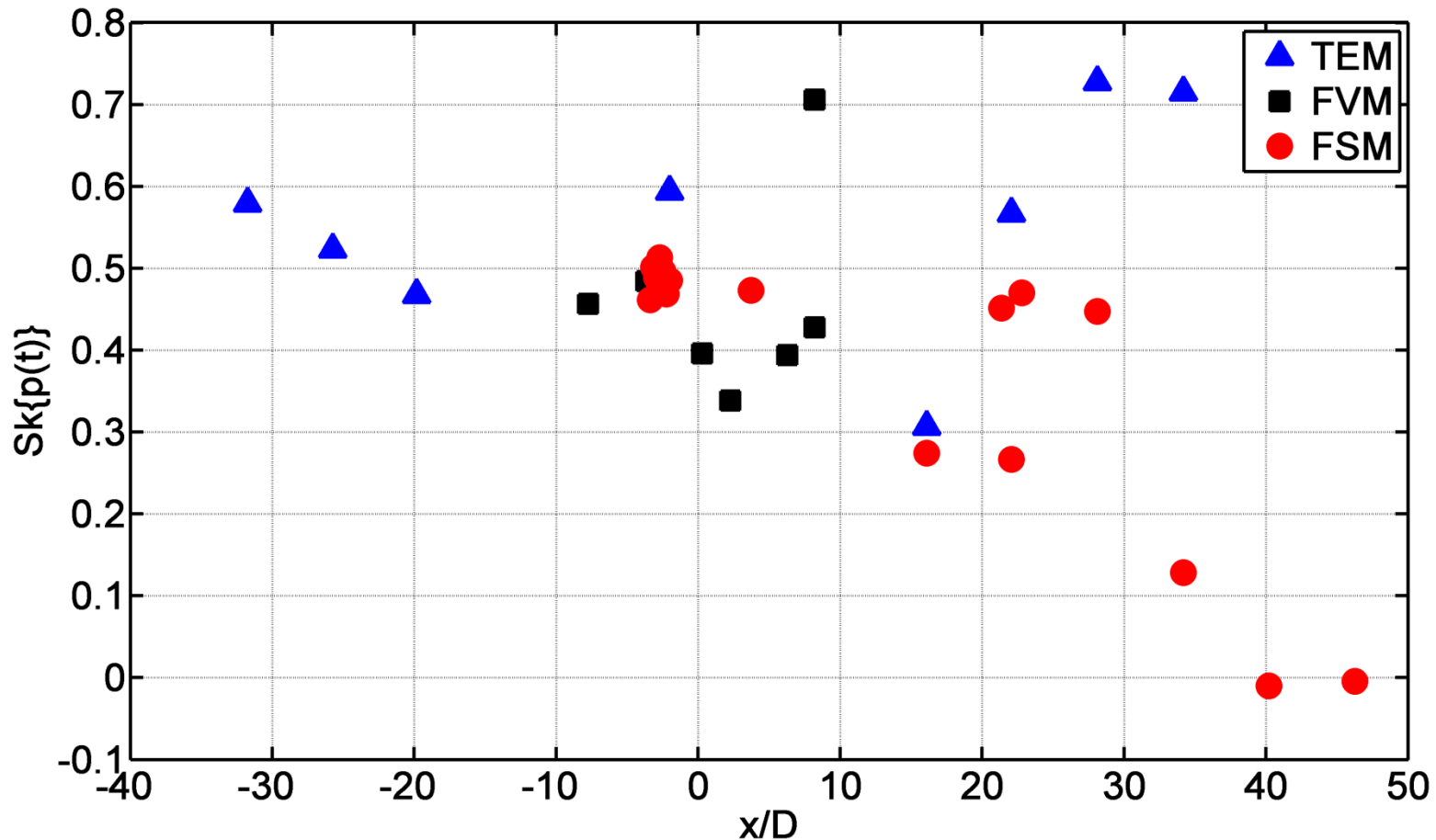
Combined Waveform Skewness

- Maximum skewness around maximum radiation region and the rapid drop-off aft.



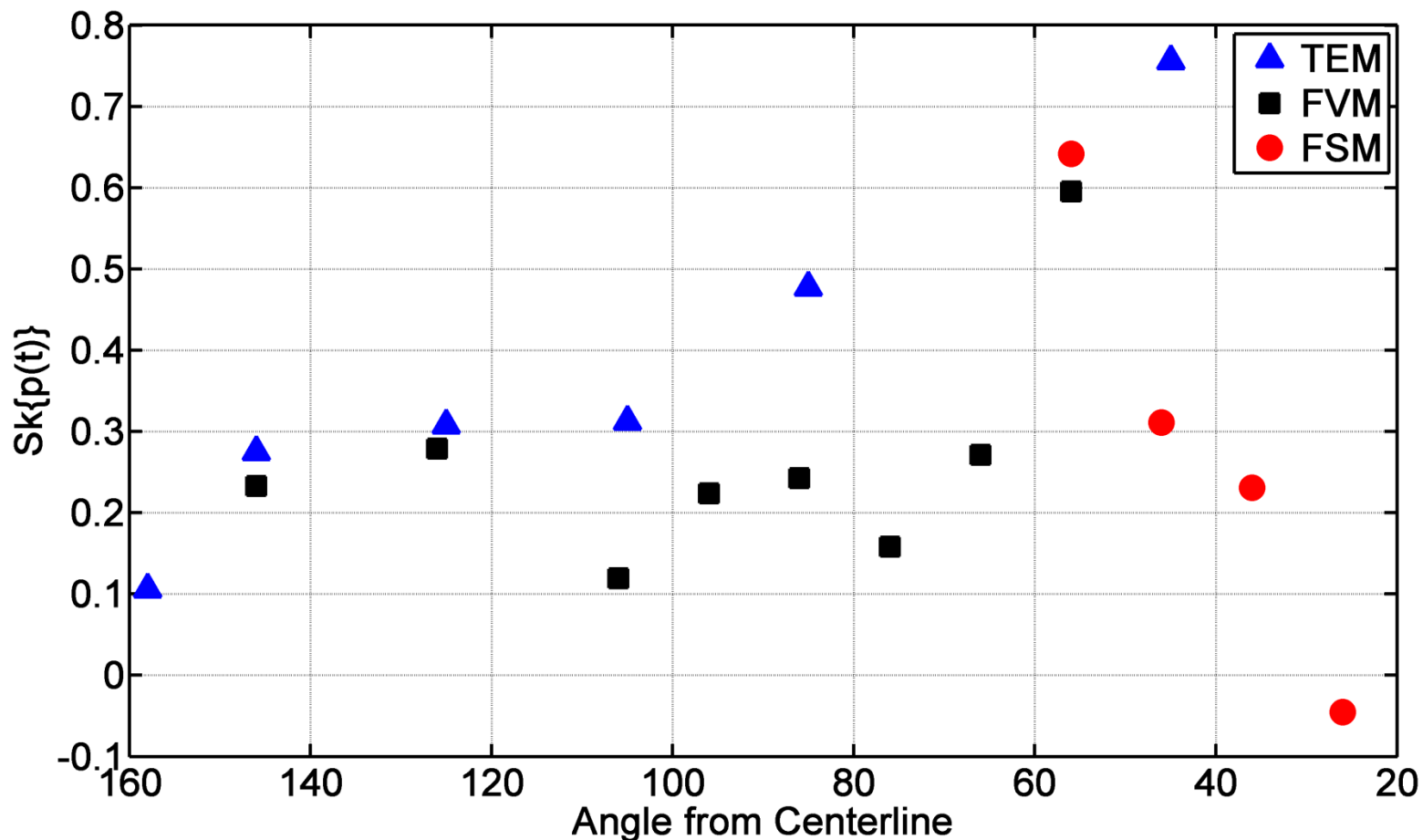
18 D Skewness

- High variability in the aft region.



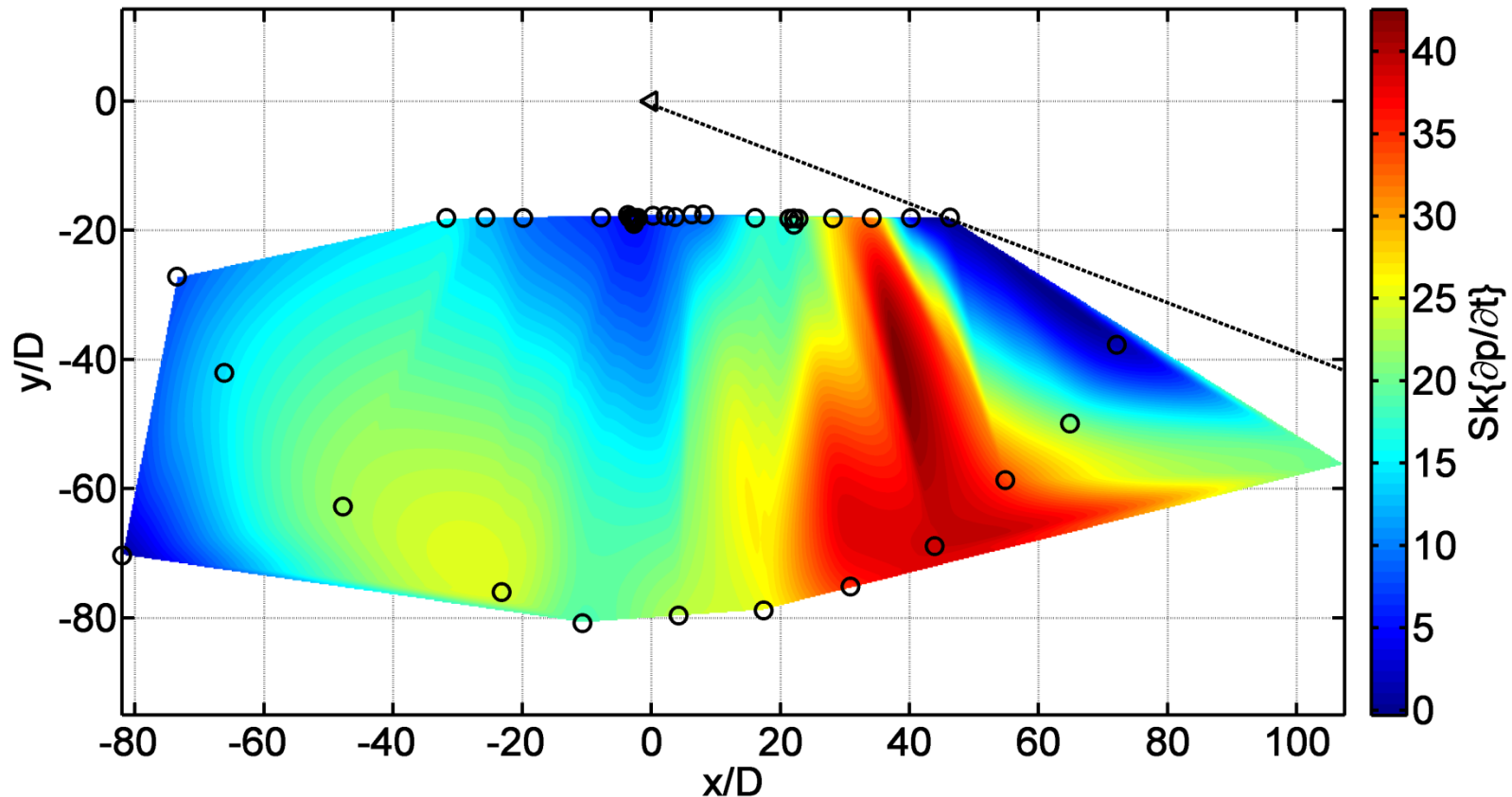
80 D Arc Skewness

- Increasing skewness from upstream to downstream until far aft angles.



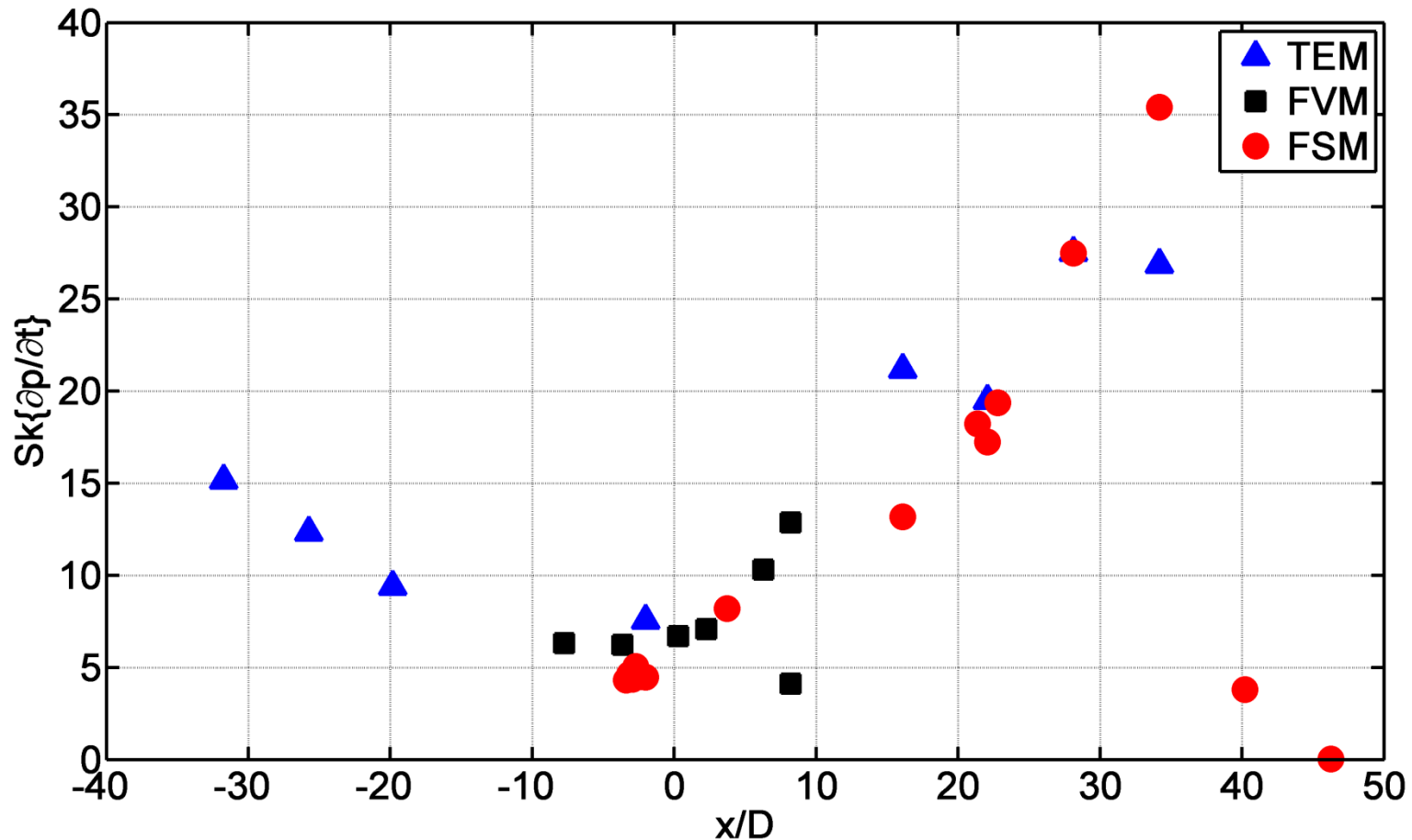
Combined Derivative Skewness

- Growth of skewness from sideline until 80 D arc, particularly in max radiation region.



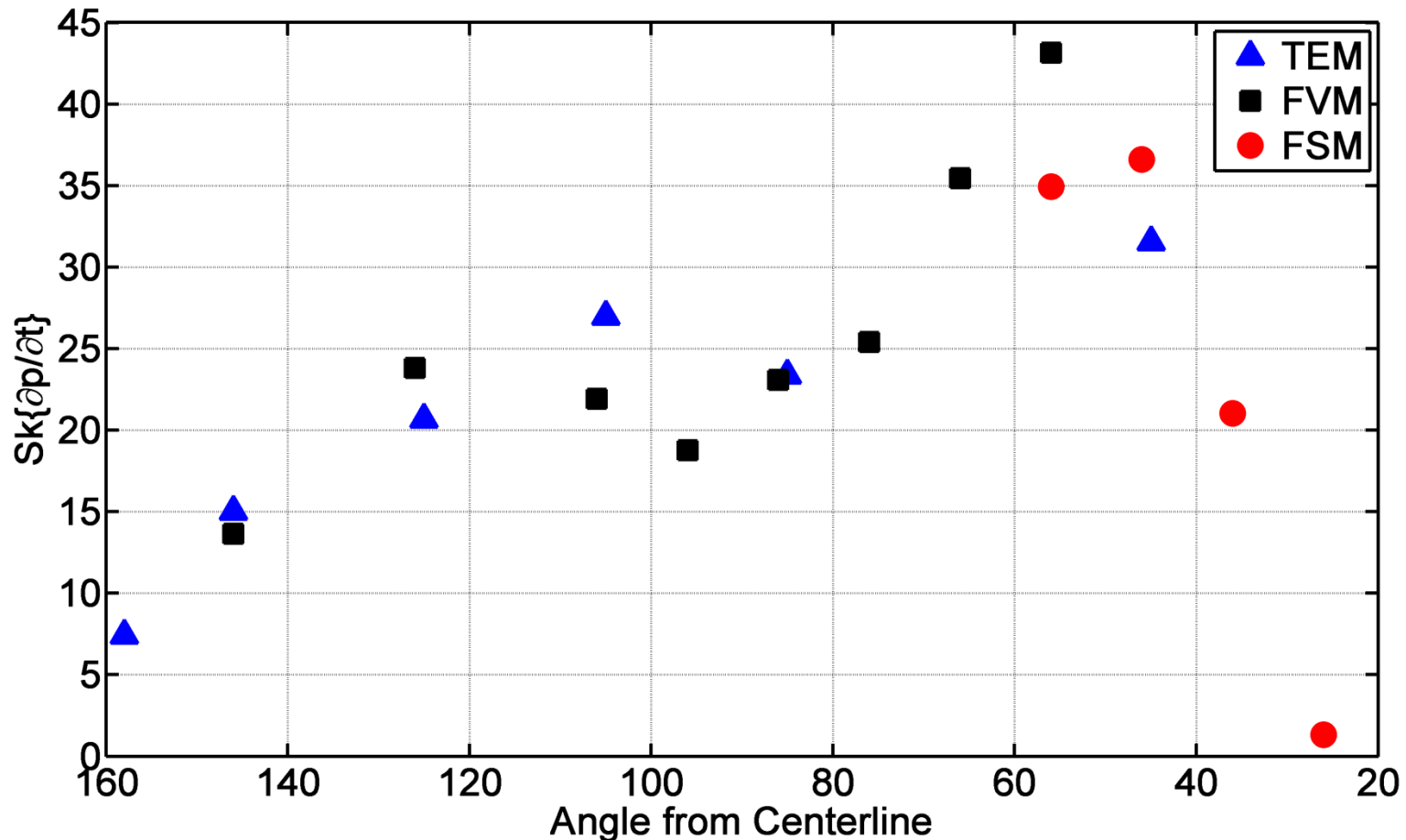
18 D Derivative Skewness

- Minimum at sideline, growth downstream until 40 D.

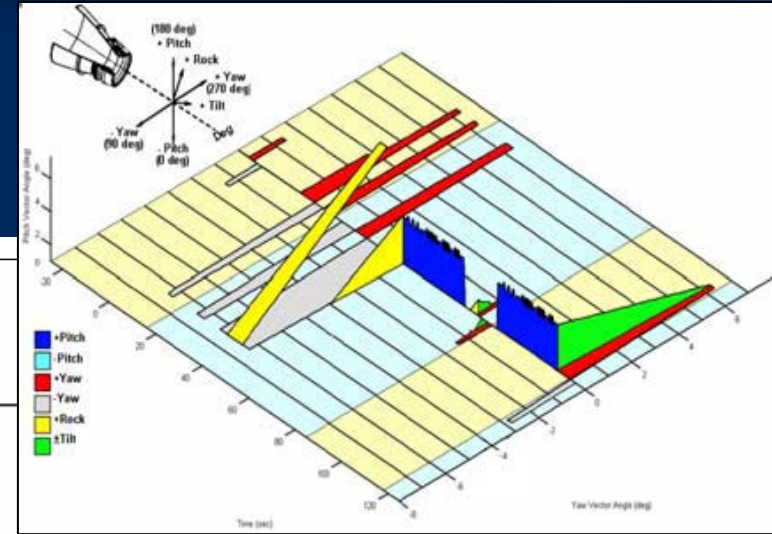
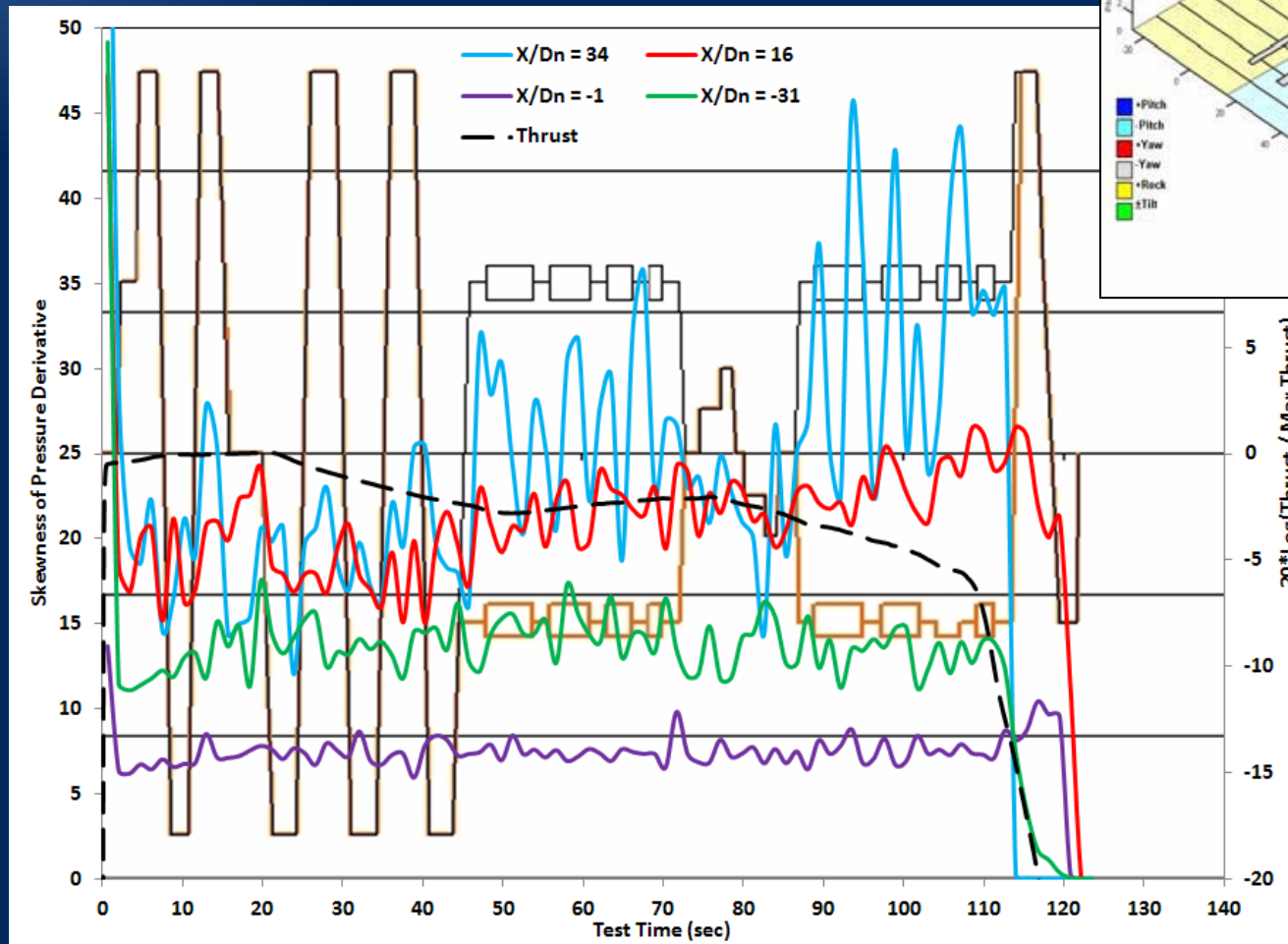


80 D Arc Derivative Skewness

- Growth going from upstream to downstream until 40°.



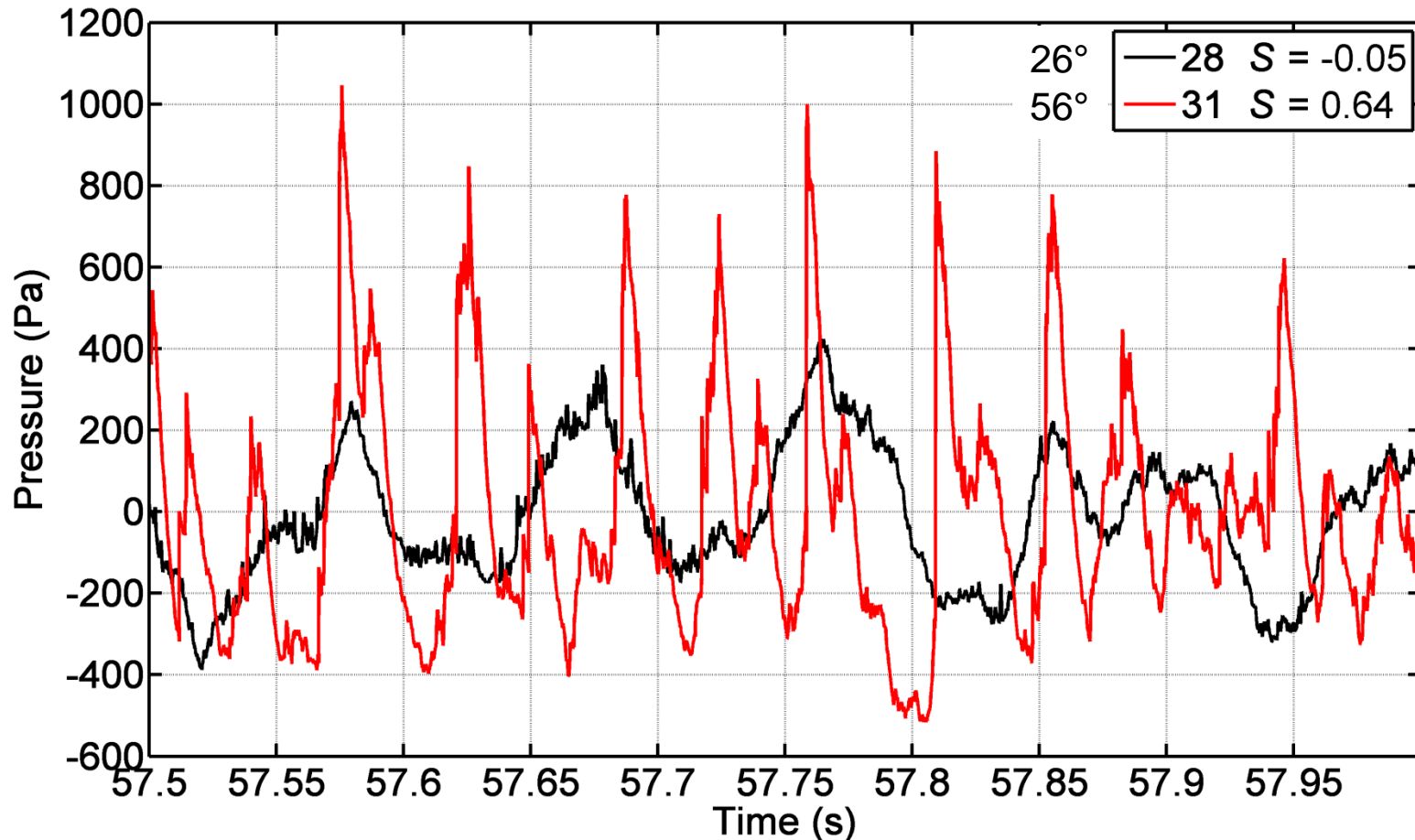
Running Derivative Skewness (TEM13)



- Why the rapid drop off in high-frequency levels, skewness, skewness of derivative at the far aft angles?
- *All extreme aft data from FSM-15*
- Comparison 26 ° and 56° data along arc (Channels 28 and 31)

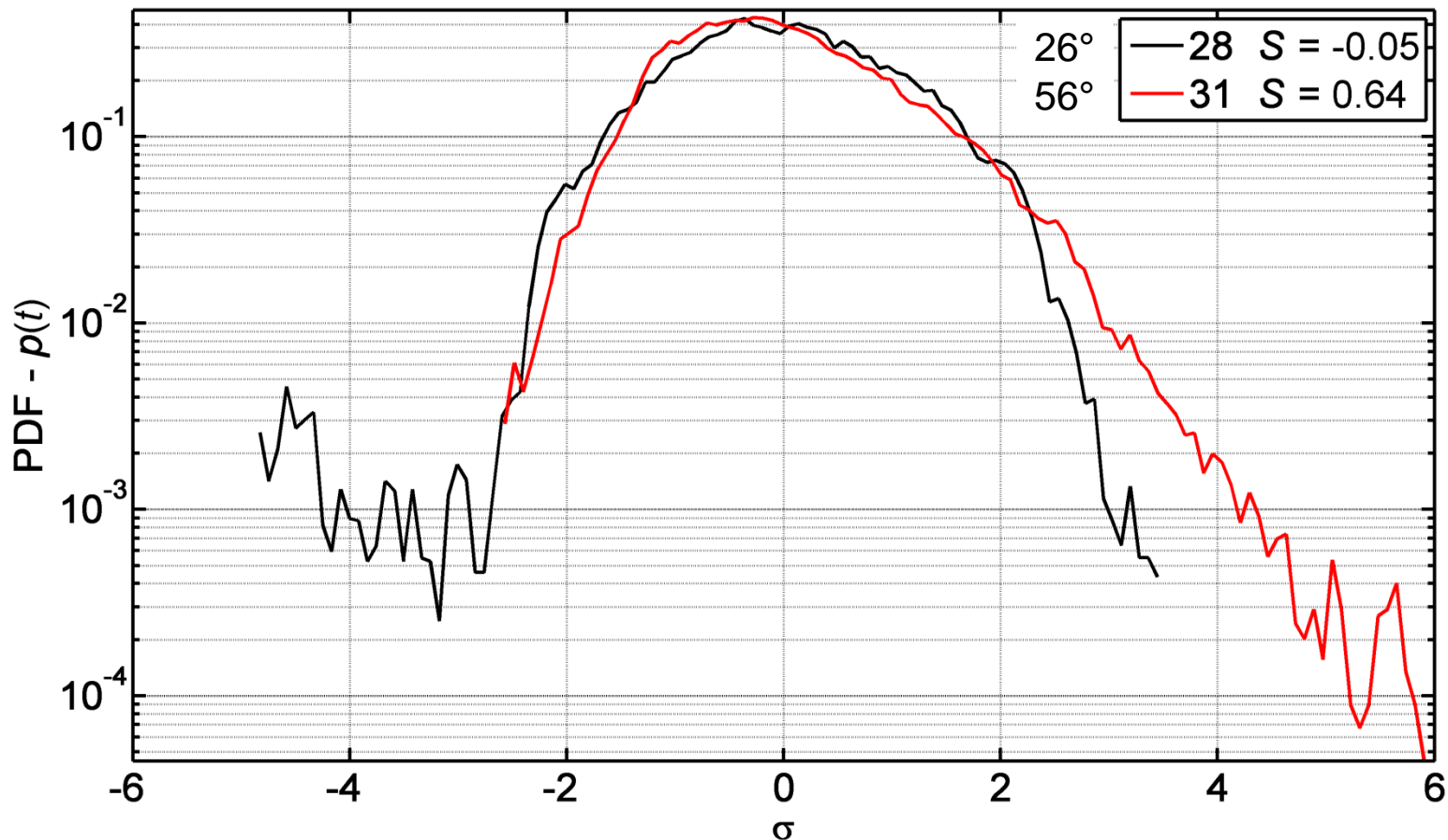
Time waveforms

- Skewed, shock-like behavior versus randomized noise, as seen in PDFs.



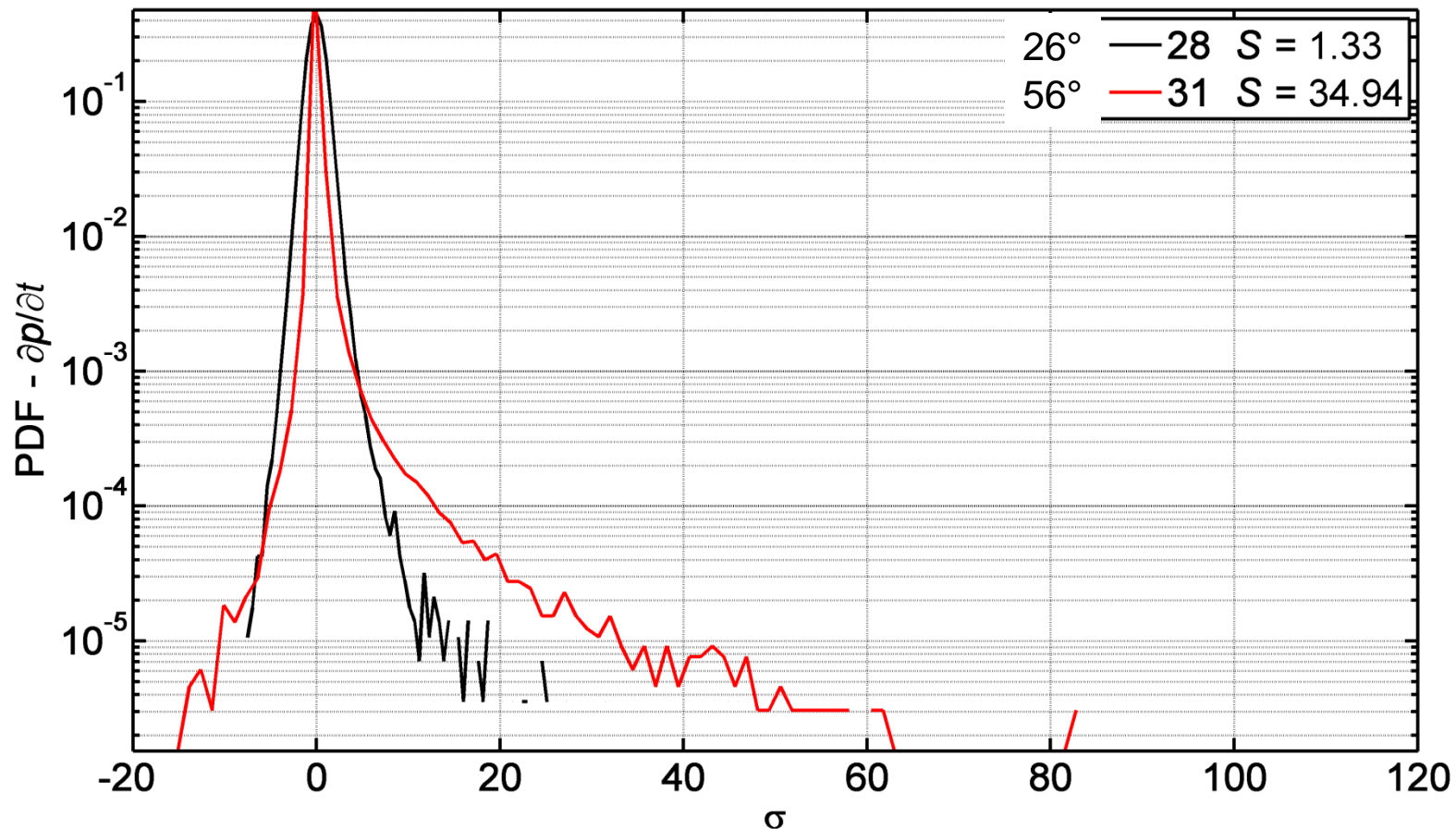
PDF of $p(t)$

- Positive skewness in maximum radiation direction, Gaussian behavior at 26° .



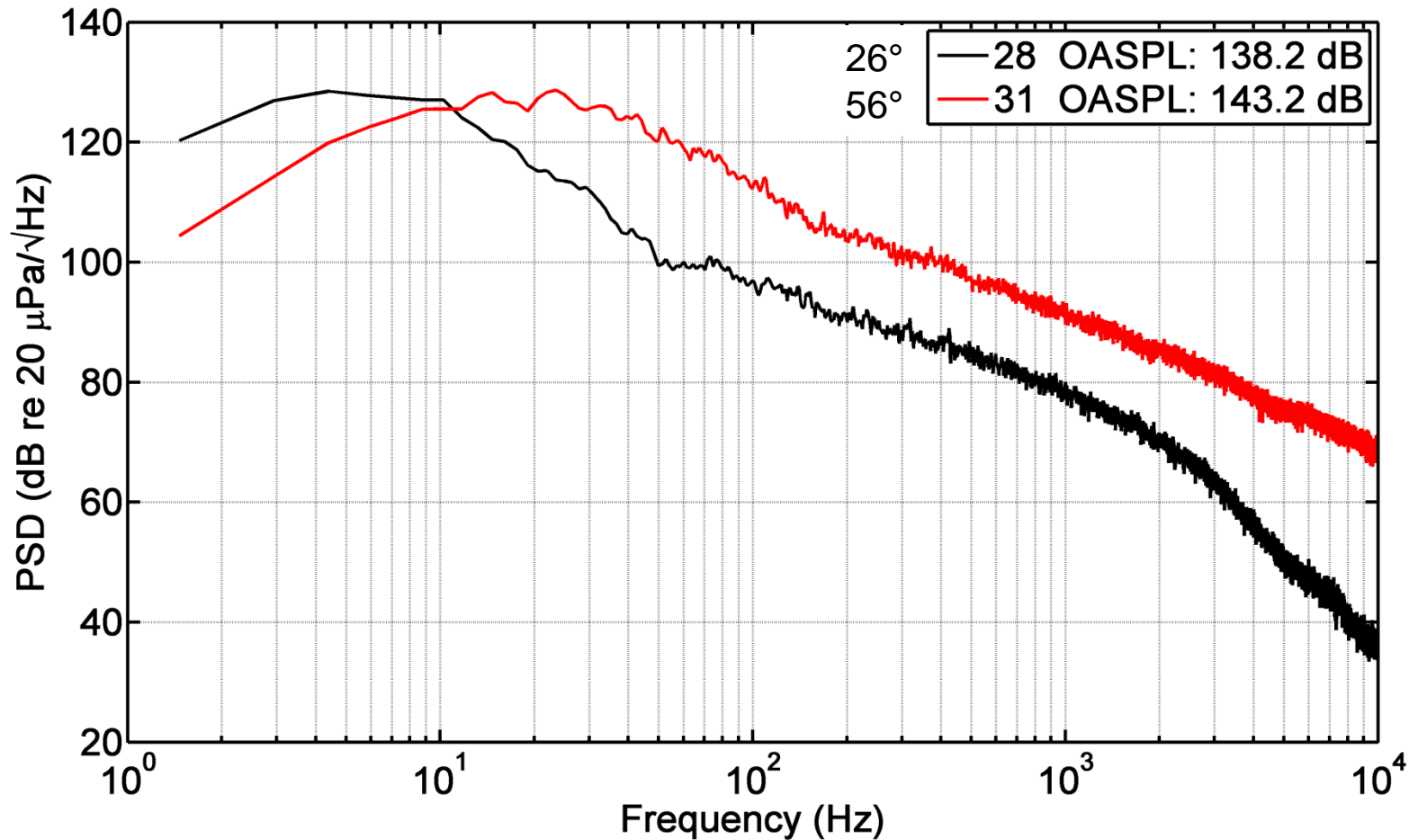
PDF of dp/dt

- Events beyond 100 standard deviations shows extreme non-Gaussian, shock-like behavior.



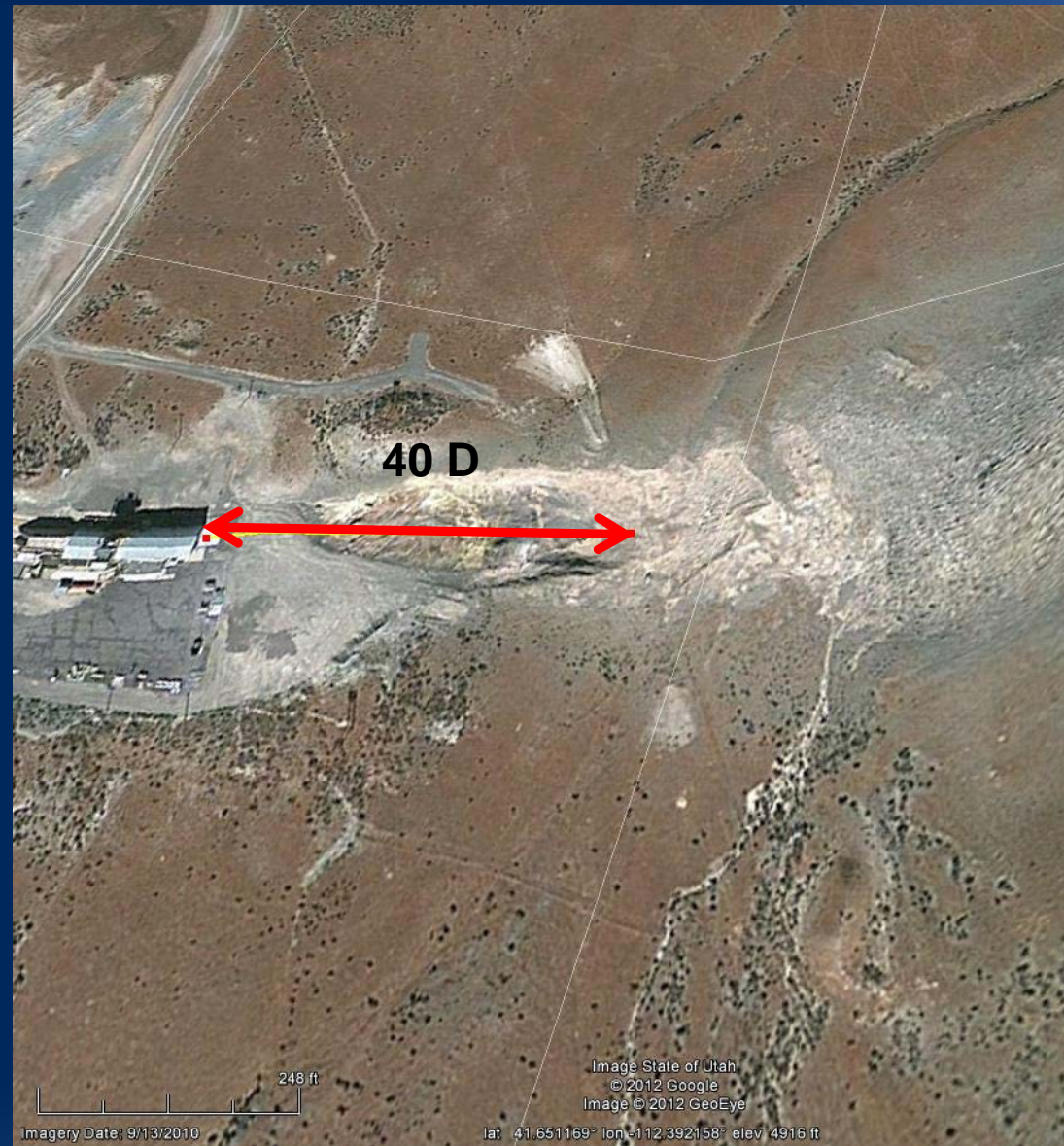
PSD Comparison

- PSDs show a marked high-frequency roll-off above 2 kHz for 26°.



Insight from Topography

- 40 D downstream is the end of the “bowl”
- Plume impingement affects high frequencies and randomizes noise generation



Conclusion

- Compilation of data from three firings show consistent behavior
- Overall maximum radiation appears to be
 - ~17-18 D downstream of nozzle
 - Along 50-60° relative to nozzle exit
- Band pressure levels seem similar above ~500 Hz
- Plume impingement from terrain and gimbaling has an impact on high-frequency levels, skewness, and derivative skewness
 - Potentially important implications for vertical launch pad environments