Preliminary Results from the QuietSpike Flight Test

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Outline

- **Previous near-field probing efforts**
- **QuietSpike near-field probing**
  - Instrumentation description
  - Data reduction
  - Measured data
    - Effects of off centerline
    - Propagation effects on centerline
- **CFD comparisons**
- **Future Efforts**

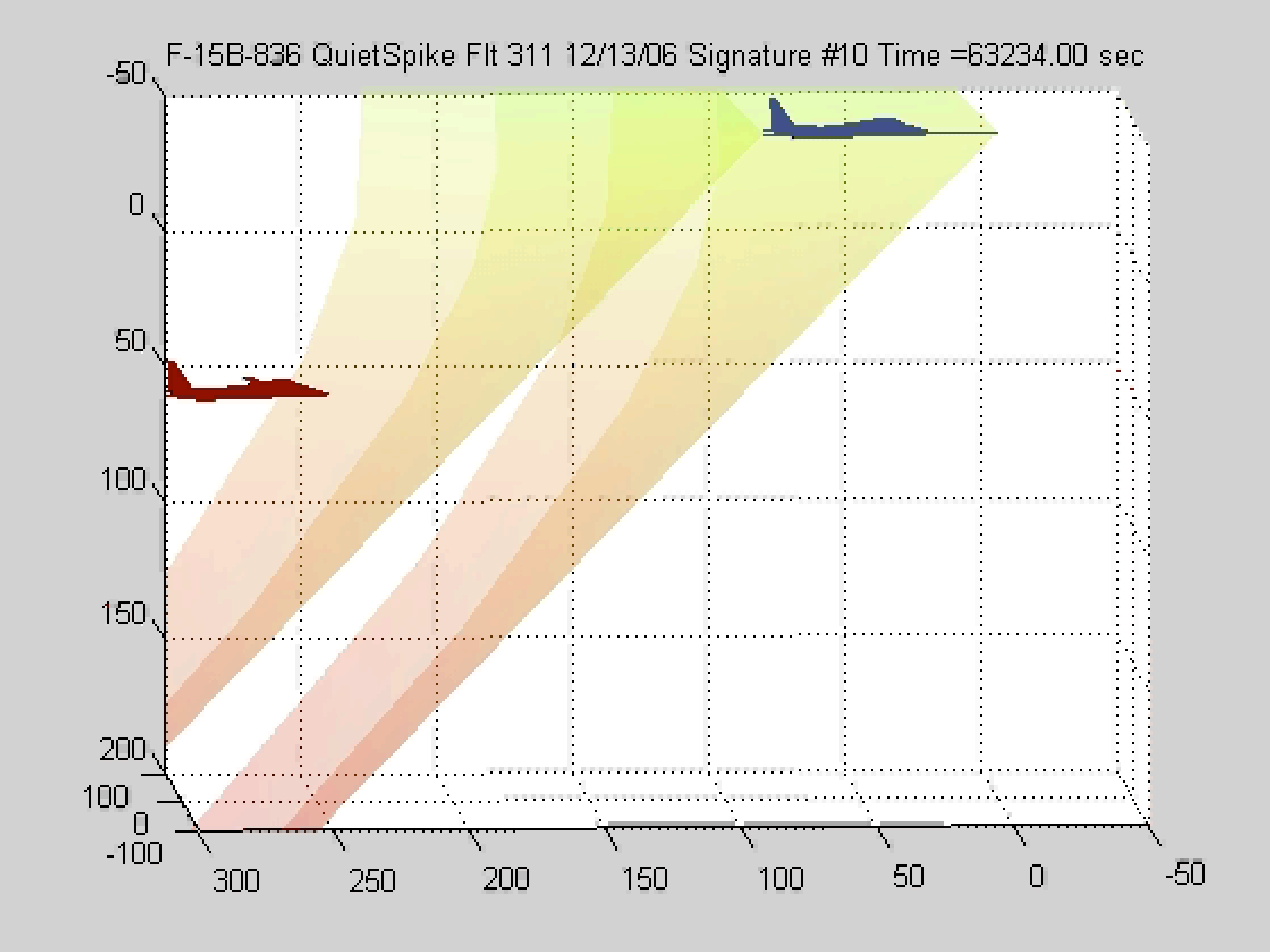
Previous Nearfield Probing Efforts

Aircraft	Researcher	Date
• F-100	Mullens	1956
• B-58, F-100, F-104	Smith	1960
• B-58 with F-100	Maglieri	1963
• F-18 with F-16XL-2	Haering	5/1993
• SR-71A with F-16XL-2	Haering	7/1993
• SR-71A with F-16XL-1 (SR-71 Sonic Boom Propagation Experiment)	Haering	2-5/1995
• F-5E with F-15B-836 (Inlet Spillage Shock Measurement)	Haering	2/2002
• SSBD with F-15B-836	Haering	8/2003 & 1/2004
• F-18 with F-15-837	Haering	7/2006

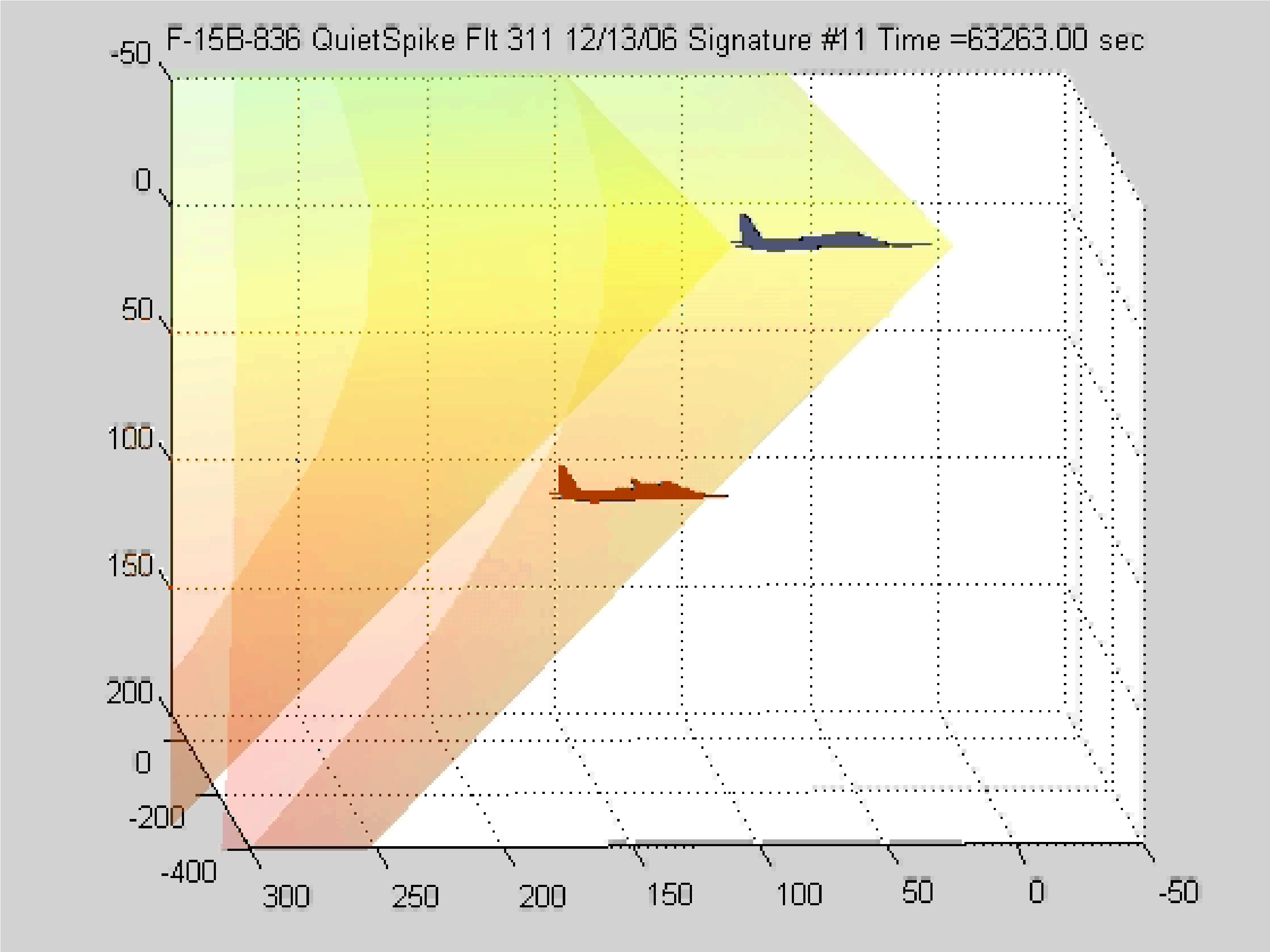
Flight Test Approach

- NASA Dryden F-15-837 probes $\phi = \pm 120°$ of QuietSpike, 79 to 662 ft flightpath separation, F-15-837 nose always behind QuietSpike tail for supersonic probing
- Probing aircraft noseboom pressures measures shock strengths
- GPS on both aircraft measures relative position
- GPS basestation for postflight carrier-phase differential corrections
- QuietSpike airdata calibration as part of envelope expansion
- GPSsonde weather balloon data, atmospheric analysis
- Pressures expressed in QuietSpike stability axes, adjusted for bow shock location

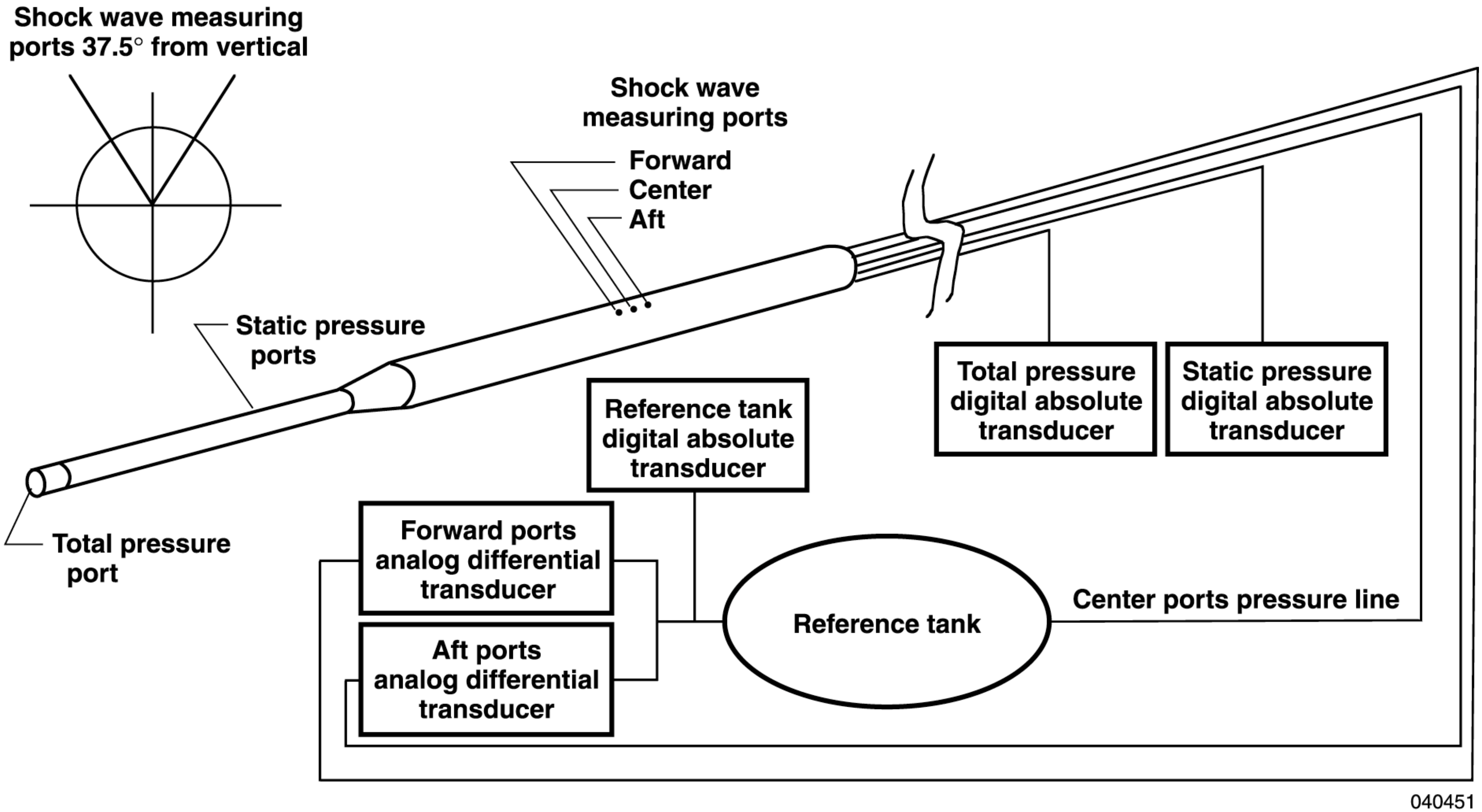
Shock Probing Back to Front



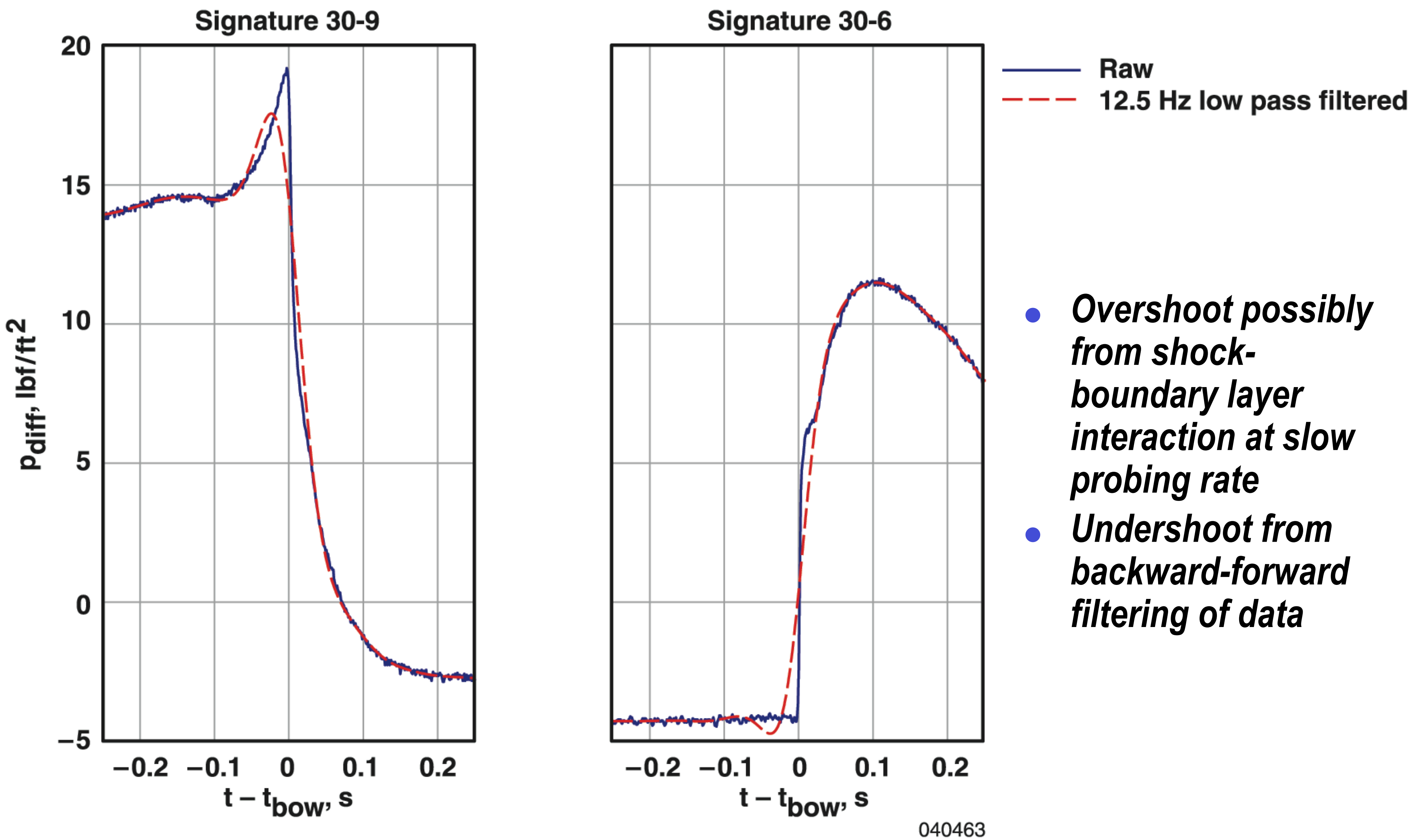
Shock Probing Front to Back



Sonic Boom Probing Noseboom



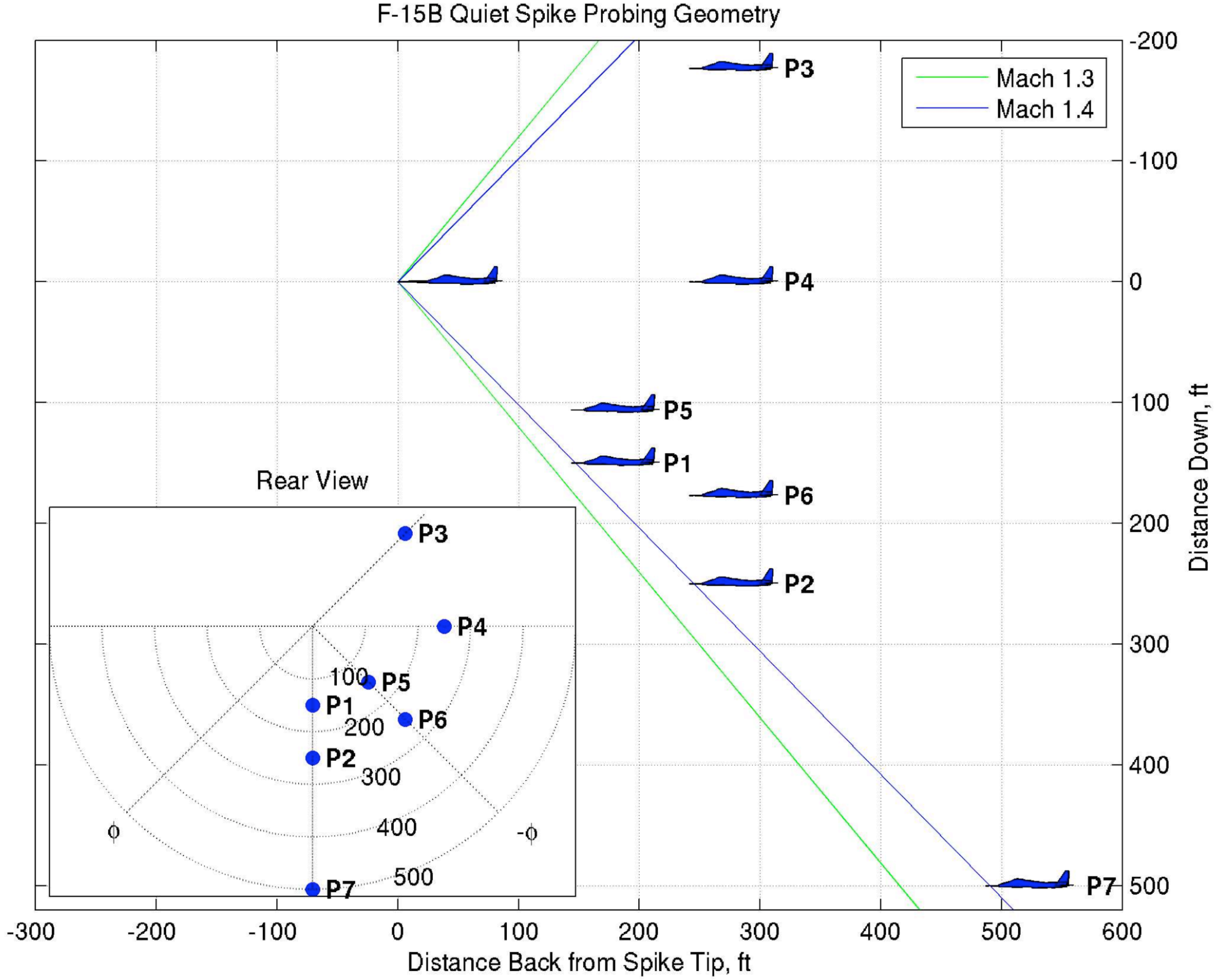
Pressure Over- Under-shoot (SSBD Data)



- *Overshoot possibly from shock-boundary layer interaction at slow probing rate*
- *Undershoot from backward-forward filtering of data*

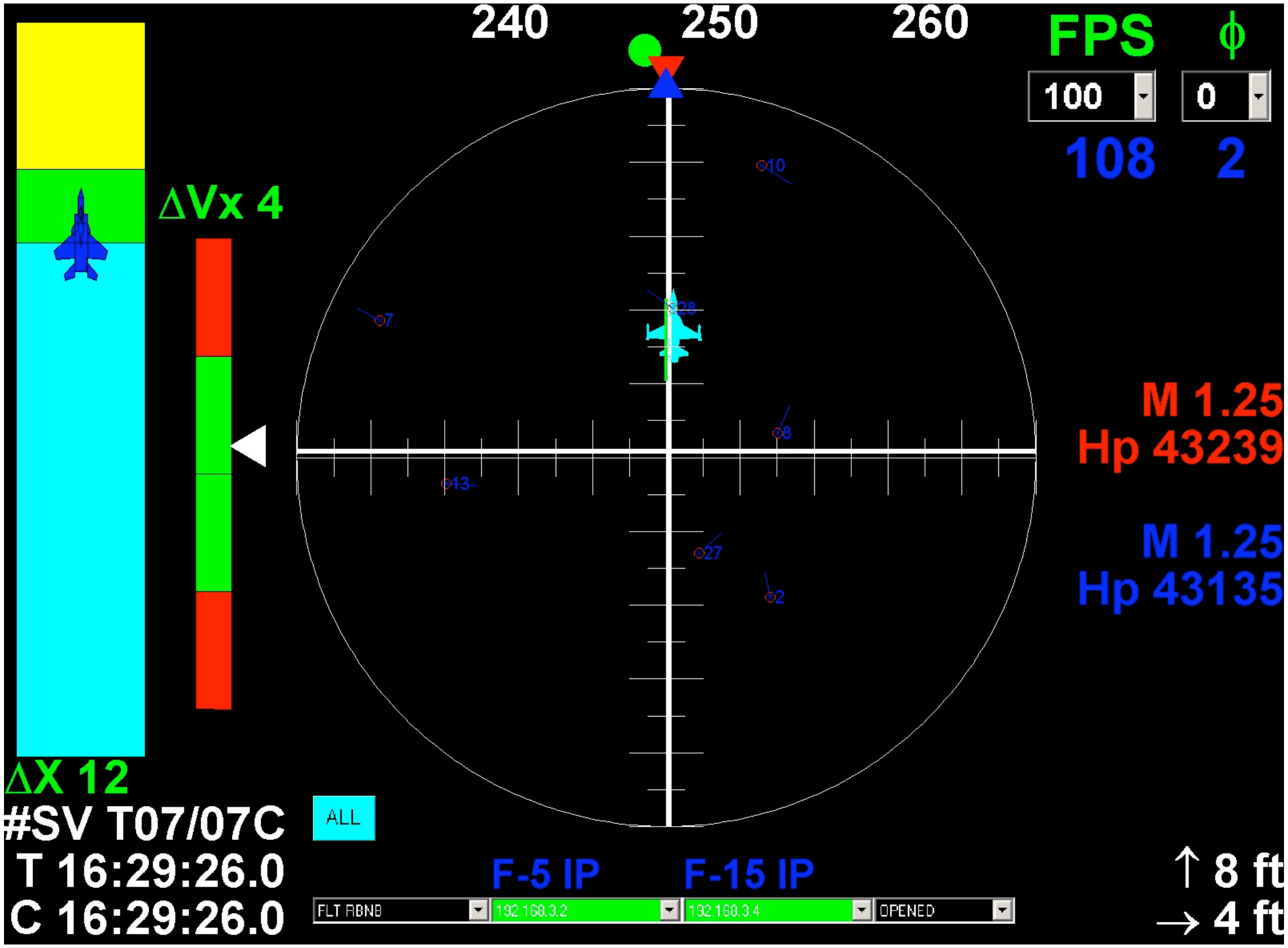
Shock Probing Orientations

- F-15-837 probes below and to side of QuietSpike, 150 to 500 ft flightpath separation, F-15-837 nose always behind QuietSpike tail for supersonic probing
- 34 probings total



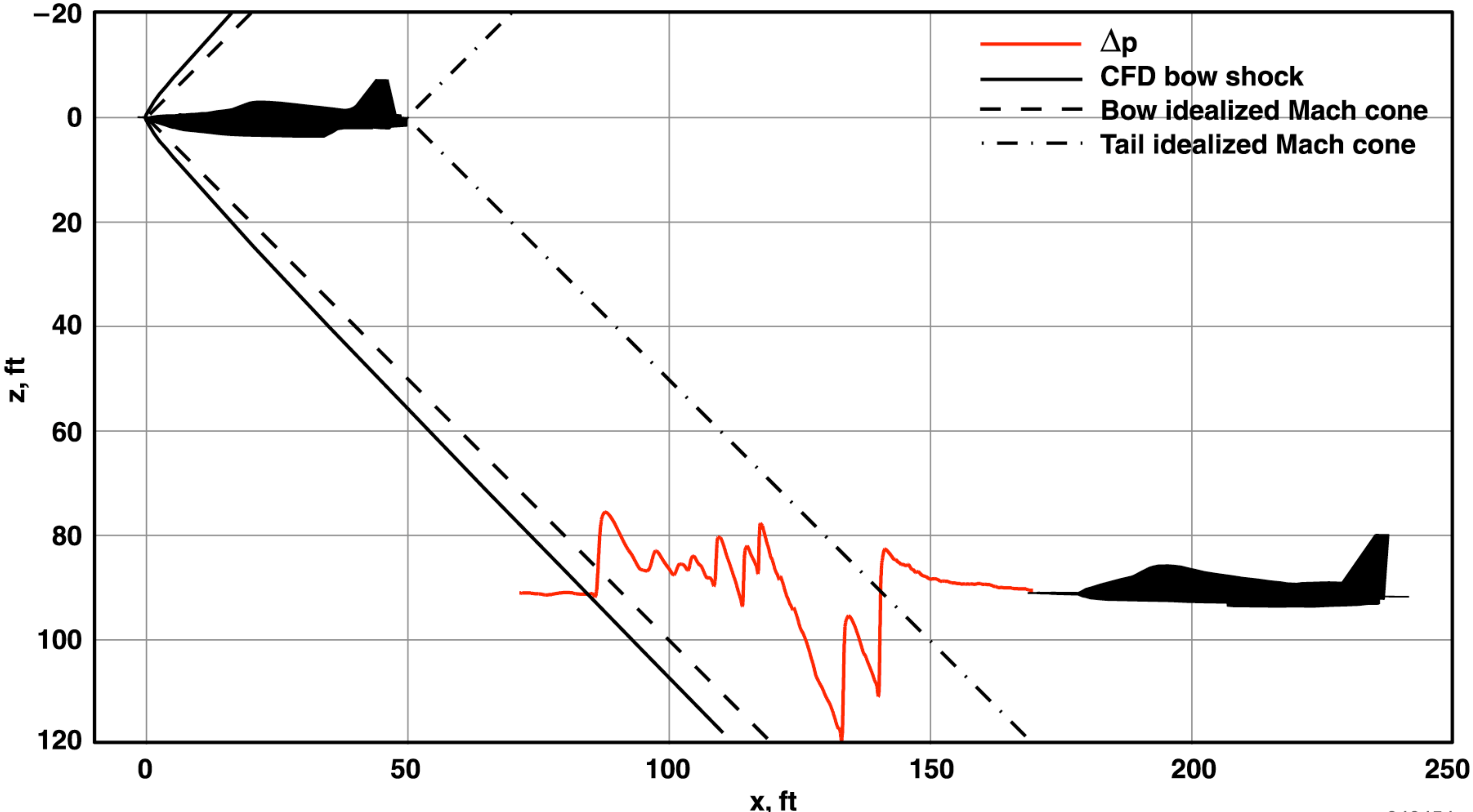
Cockpit Shockwave Position Display

- Schlieren computer, flown on F-18B-846, mounted in rear cockpit of F-15-837
- Rear seater can suggest fine position and rate adjustments
- Enhances test point efficiency and quality, not required for flight



Example Data from SR-71 / F-16XL

Shock Position Geometry (SSBD Data)



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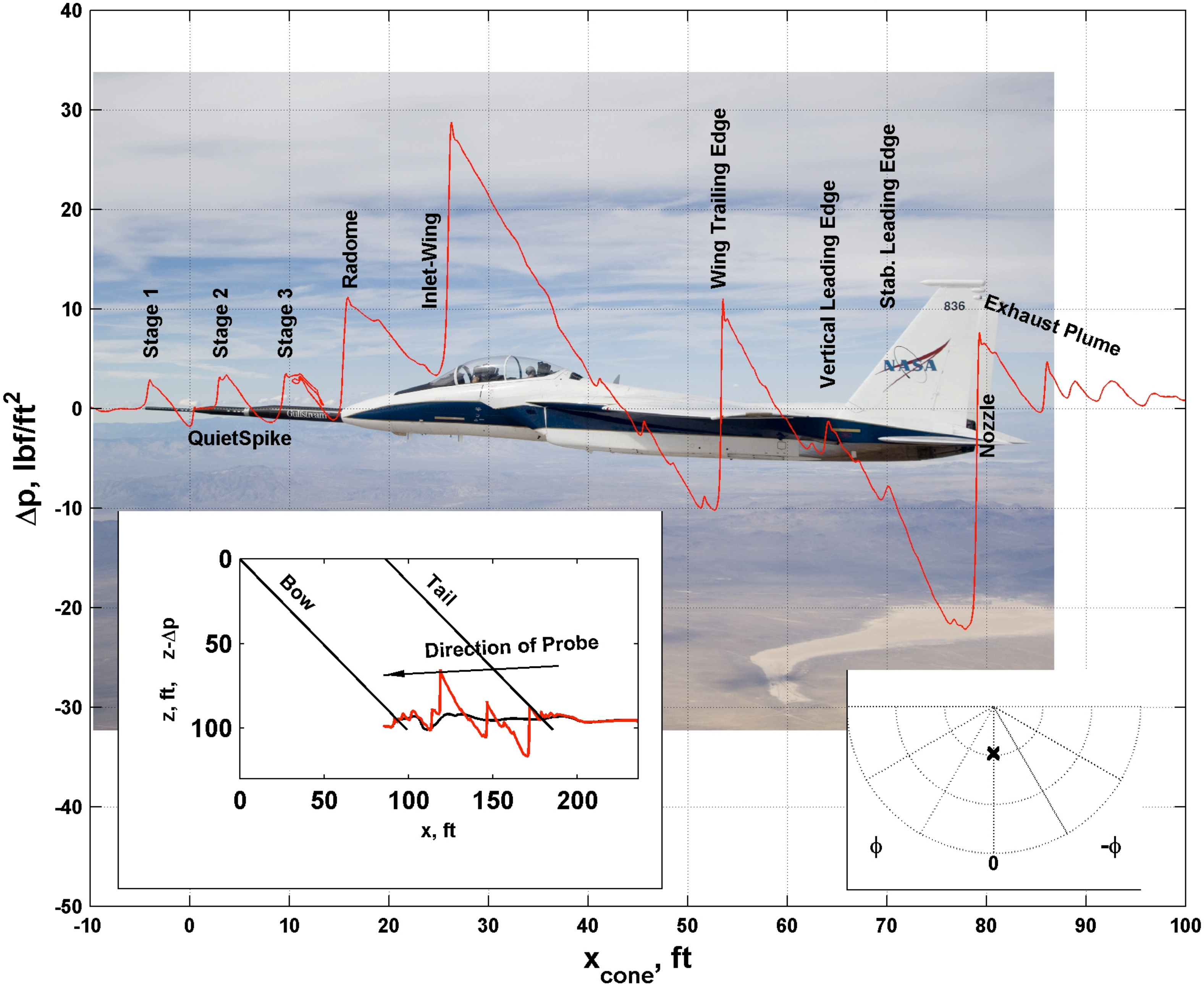
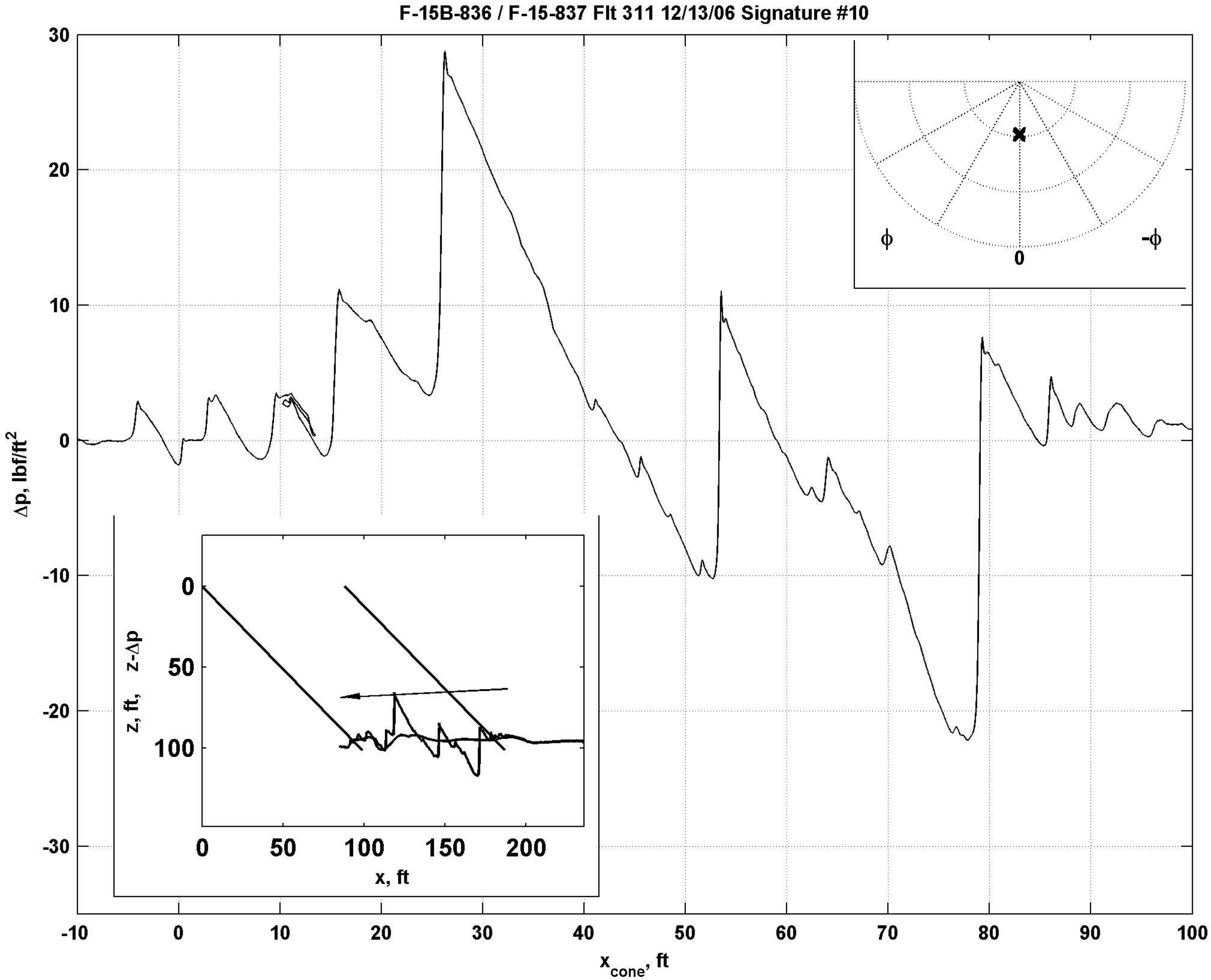
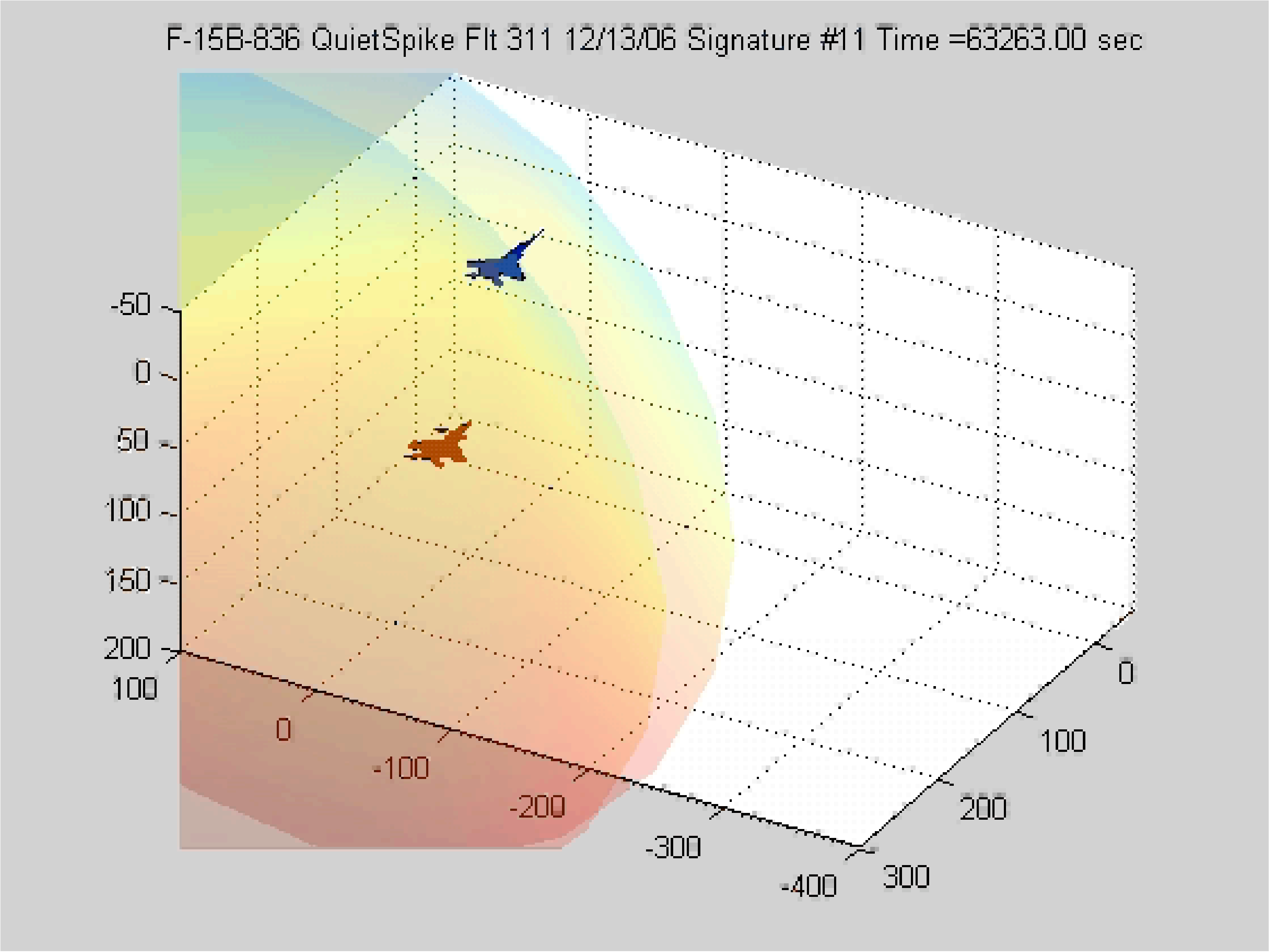
F-15B-836 QuietSpike 12/13/06 Signature #10



Near-Field Probing Directly Under



Animation of Signature 11 Probing, Rear Quarter View



Near-Field Probing Directly Under, Back-Up

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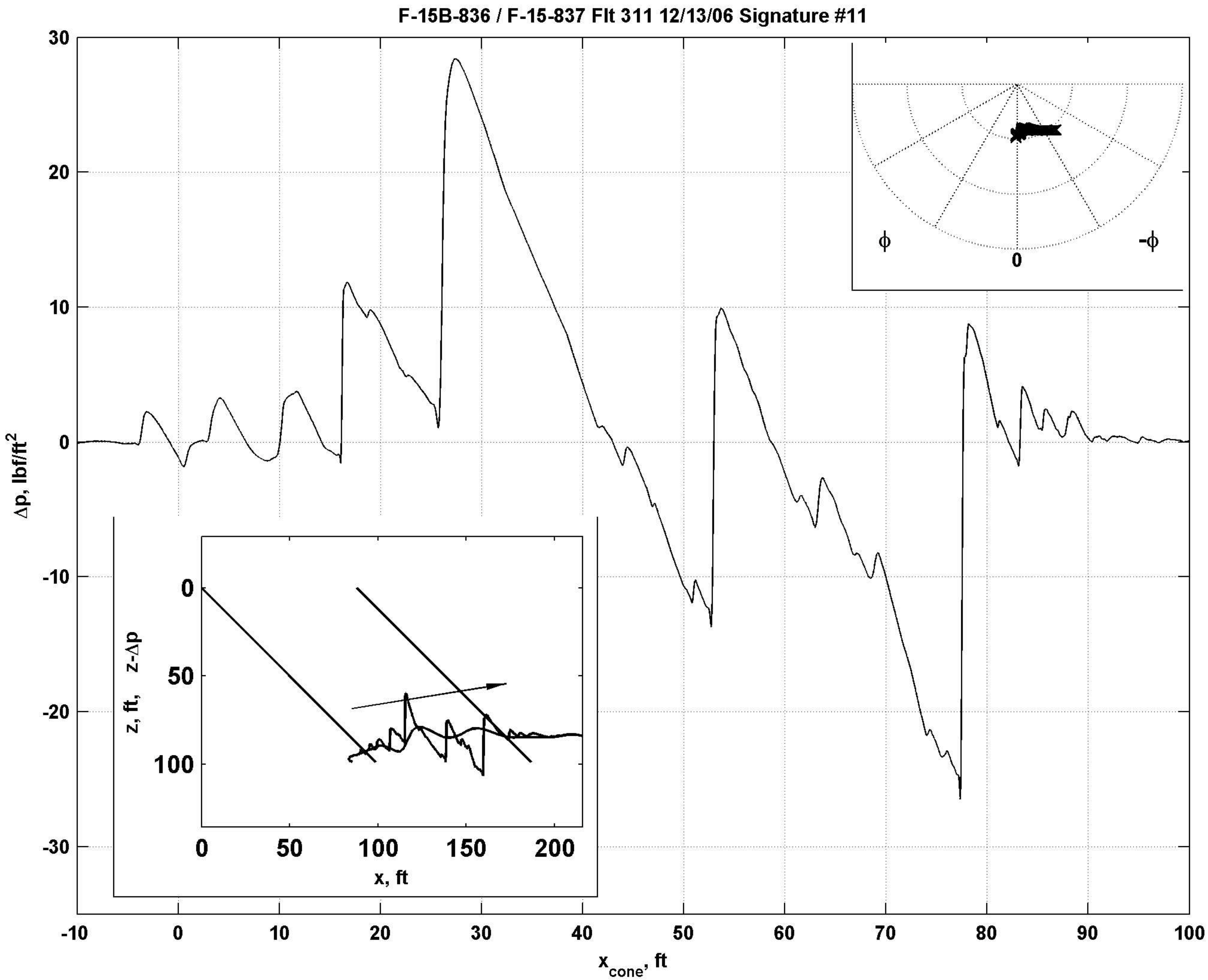
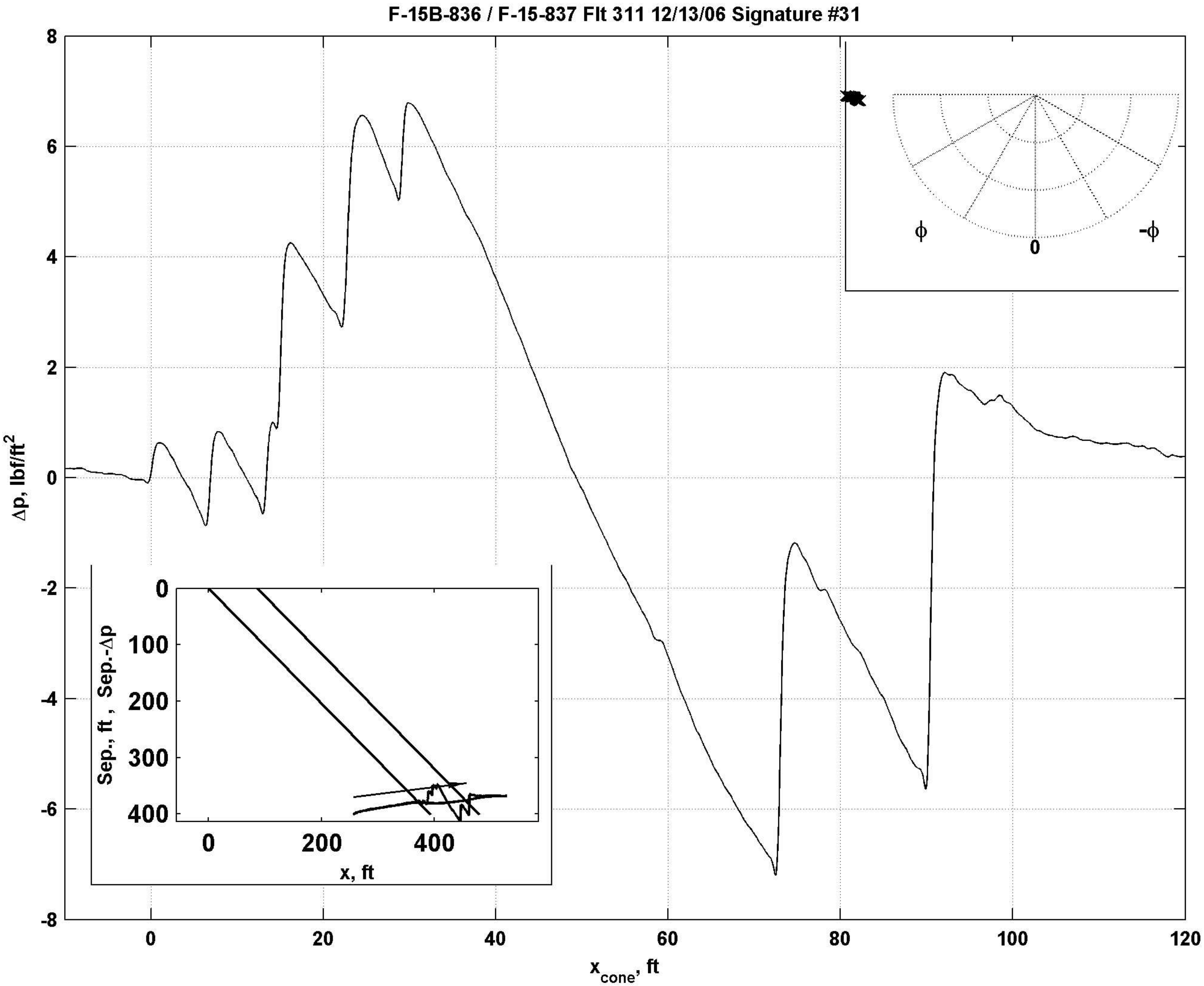
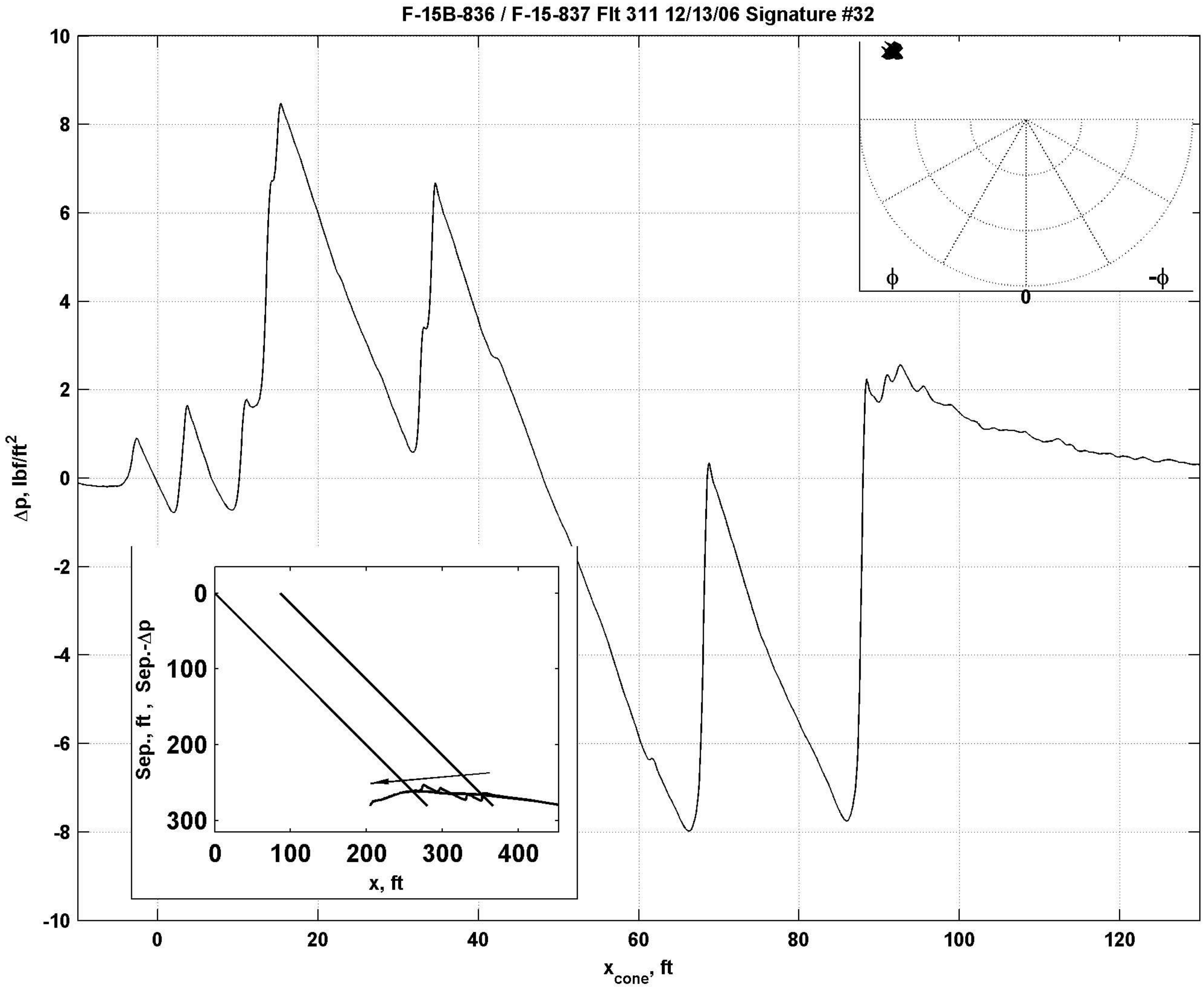
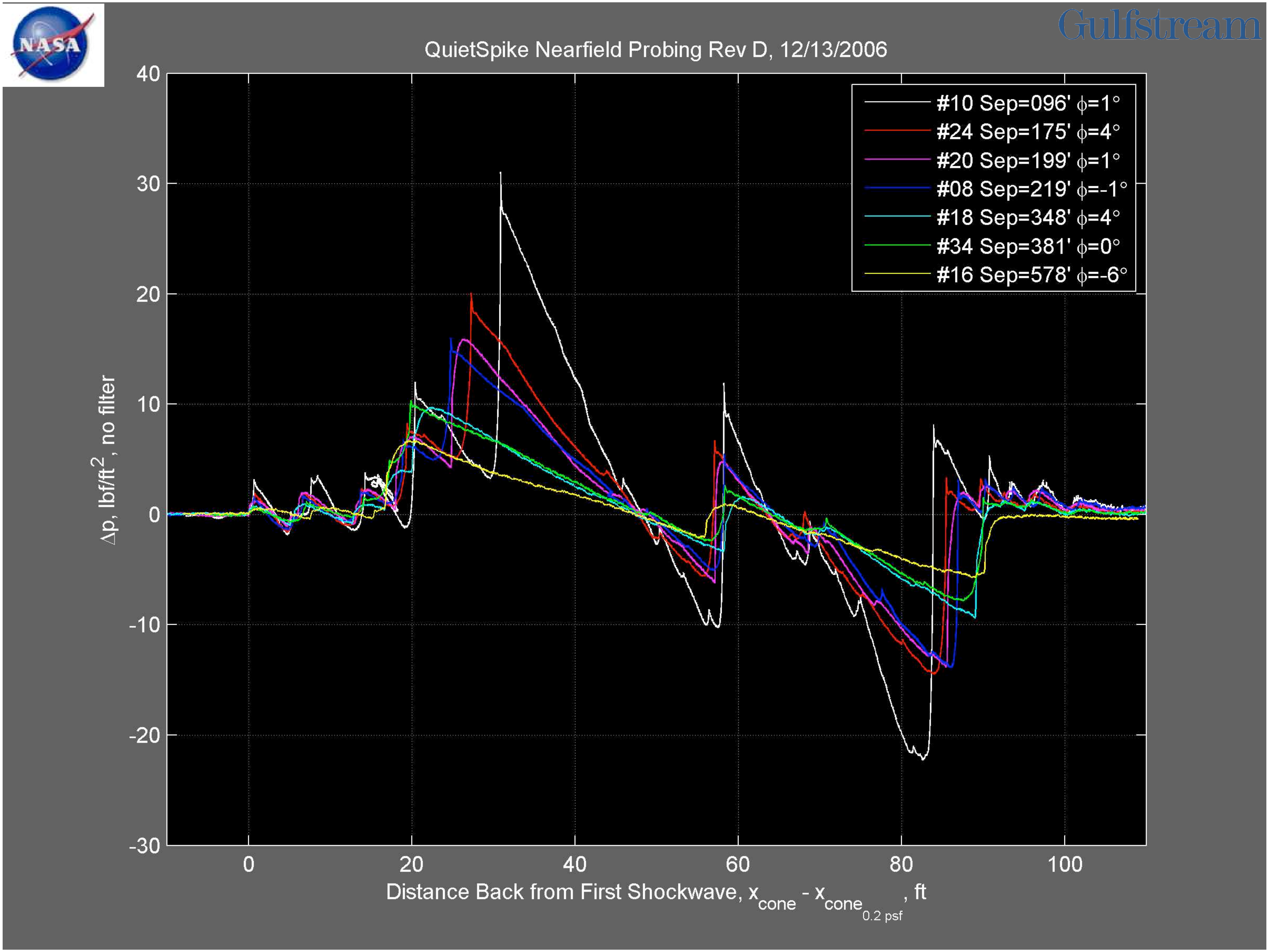


Near-Field Probing to Side

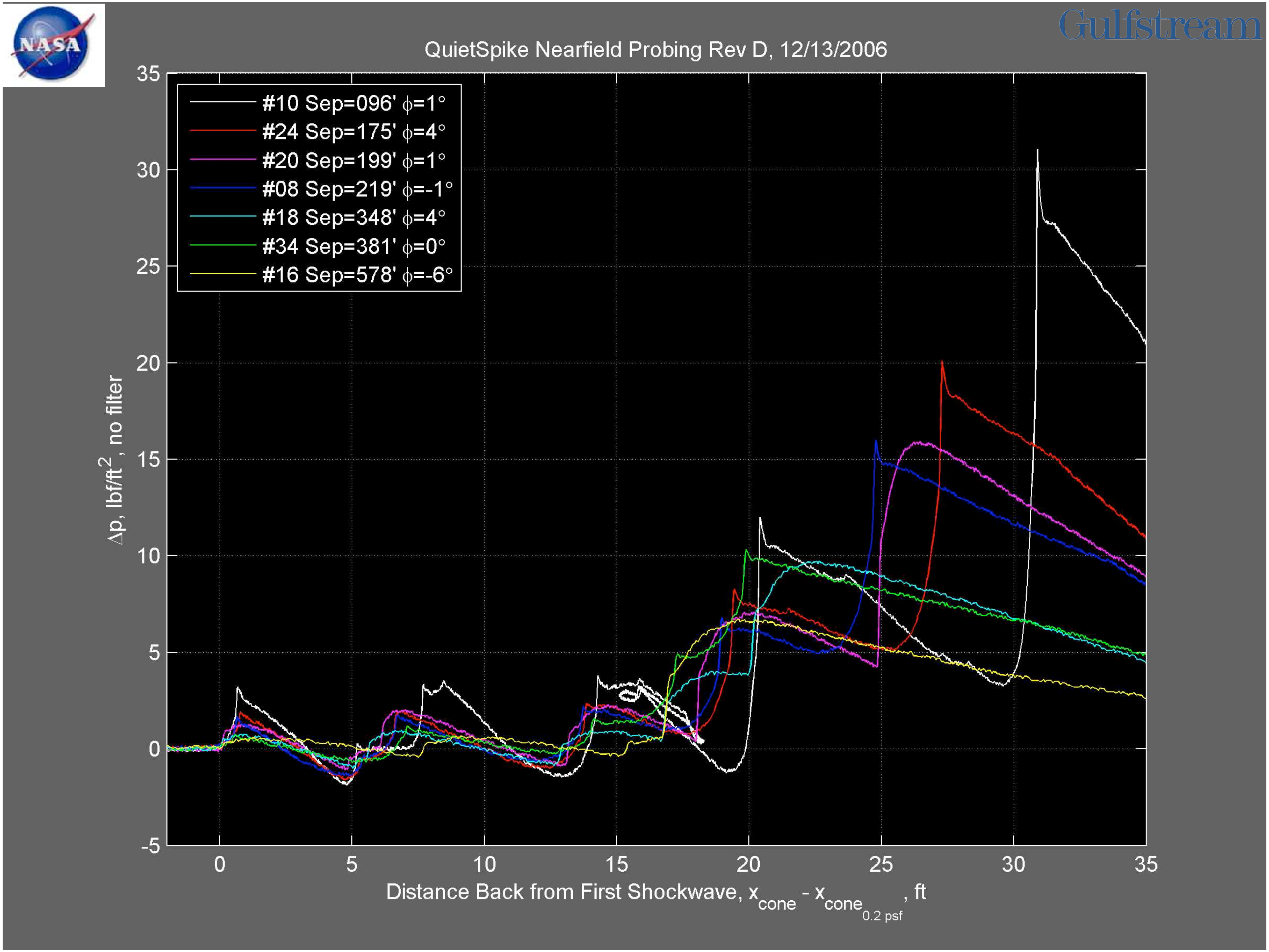


Near-Field Probing Above and to Side





Gulfstream
QuietSpike Nearfield Probing Rev D, 12/13/2006
#10 Sep=096' ϕ=1°
#24 Sep=175' ϕ=4°
#20 Sep=199' ϕ=1°
#08 Sep=219' ϕ=-1°
#18 Sep=348' ϕ=4°
#34 Sep=381' ϕ=0°
#16 Sep=578' ϕ=-6°
Δp, lbf/ft², no filter
Distance Back from First Shockwave, $x_{cone} - x_{cone_{0.2\ psf}}$, ft
40
30
20
10
0
-10
-20
-30
0
20
40
60
80
100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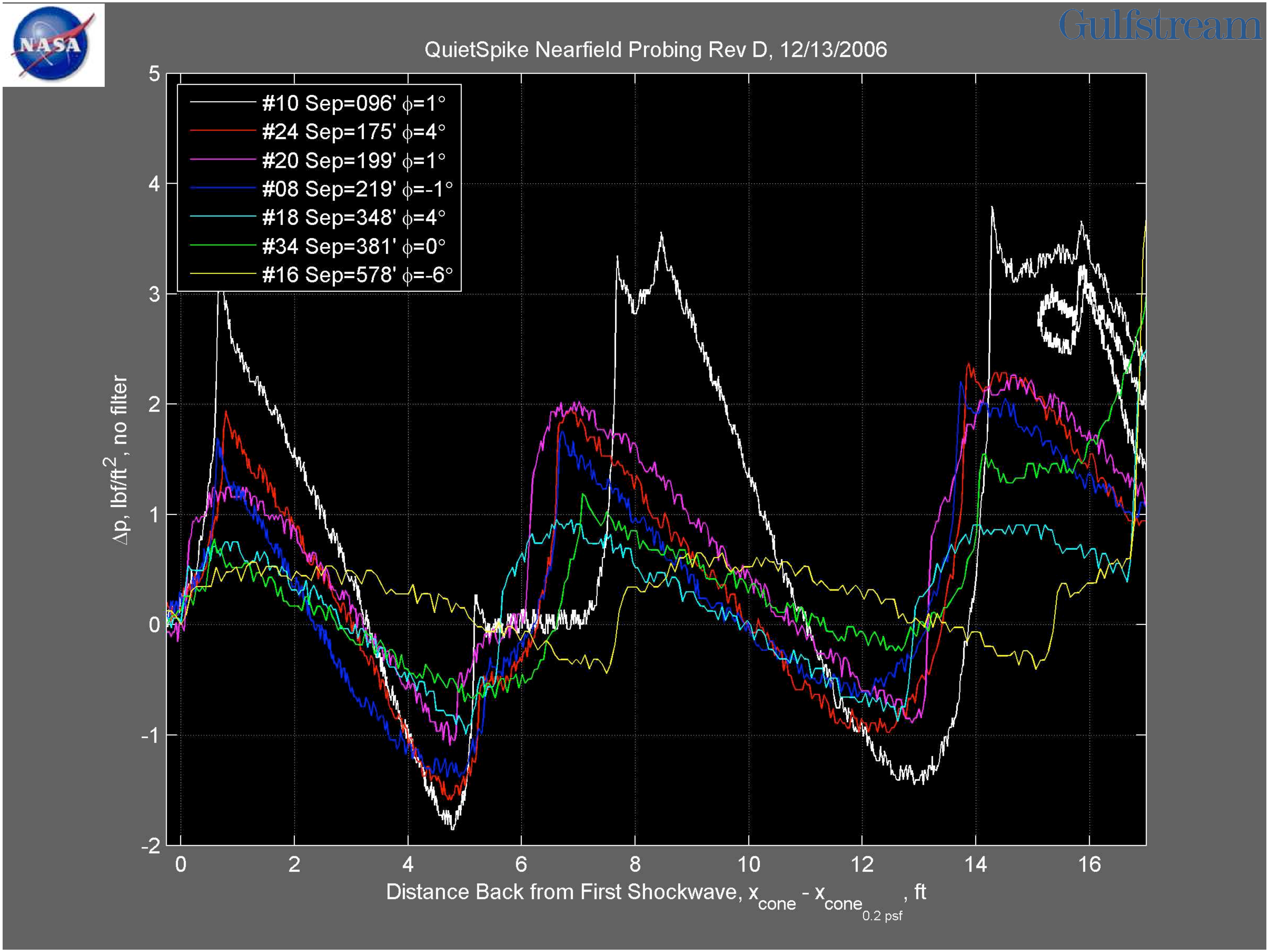
#18 Sep=348' ϕ=4°
#34 Sep=381' ϕ=0°
#16 Sep=578' ϕ=-6°
Δp, lbf/ft², no filter
Distance Back from First Shockwave, x cone - x cone 0.2 psf, ft
35
30
25
20
15
10
5
0
-5
0
5
10
15
20
25
30
35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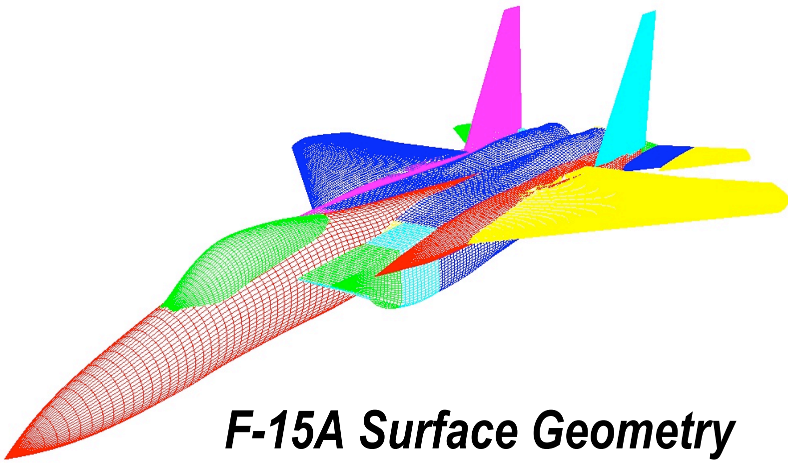
#18 Sep=348' ϕ=4°
#34 Sep=381' ϕ=0°
#16 Sep=578' ϕ=-6°
Δp, lbf/ft², no filter
Distance Back from First Shockwave, $x_{cone} - x_{cone_{0.2\ psf}}$, ft
5
4
3
2
1
0
-1
-2
0
2
4
6
8
10
12
14
16

CFD Comparisons

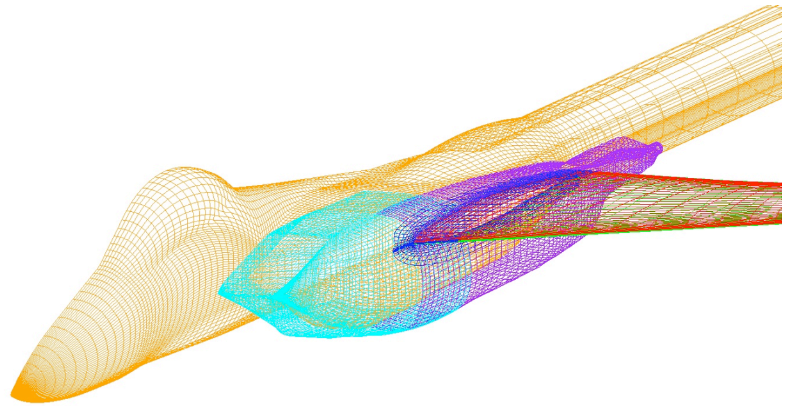
- ***Two CFD methods used to analyze F-15B w/ Quiet Spike***
- ***Composite 3-D/Axisymmetric***
  - *Low resolution unstructured surface pressure analysis*
  - *High resolution structured analysis of resulting equivalent area*
- ***Hybrid Unstructured/Structured Fully 3-D***
  - *USM unstructured near field out to ~1/3 body length*
  - *3-D high resolution structured mid-field*
- ***CFD Flight Conditions:***
  - *All cases run at Mach 1.400, sig. #10* M_{avg} *= 1.401 (-.006 / +.008)*
  - *CFD run at* $\alpha = 1.8^{o}$*,*
  - *Small deviations in AOA between CFD and flight are corrected by shifting signature in X (at 95 ft,* $\Delta\alpha = 0.1^{o}$ *is* ΔX *= 4 inches)*

F-15B CFD Geometry

- CFD models built from DFRC supplied geometry

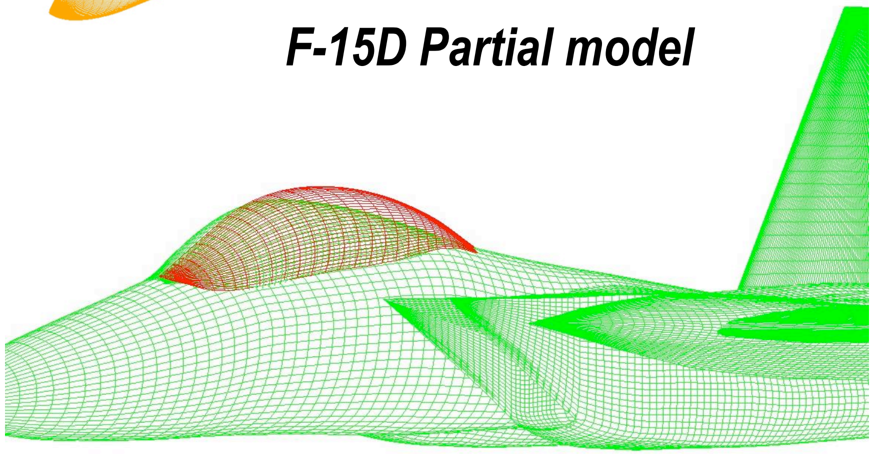


F-15A Surface Geometry



F-15D Partial model

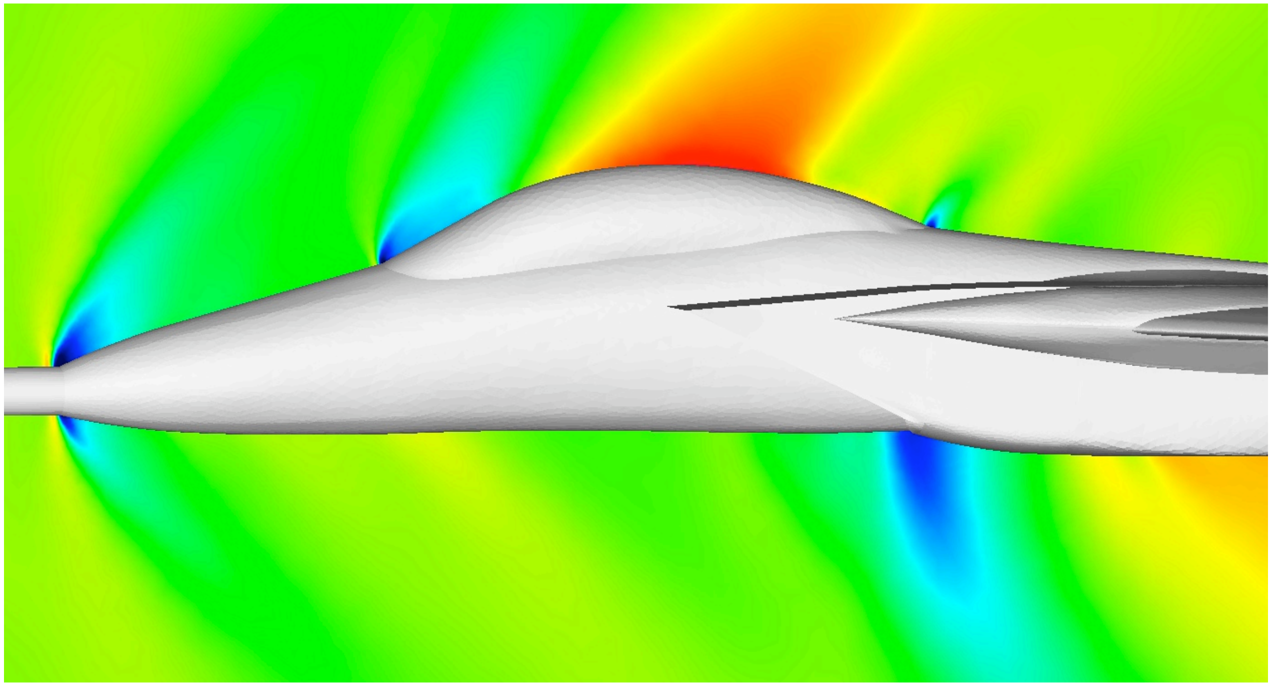
Canopy from the F-15D model was grafted onto the F-15A geometry to create the F-15B configuration



Accuracy of the geometry is unknown
Smoothness of the geometry is ….. not very

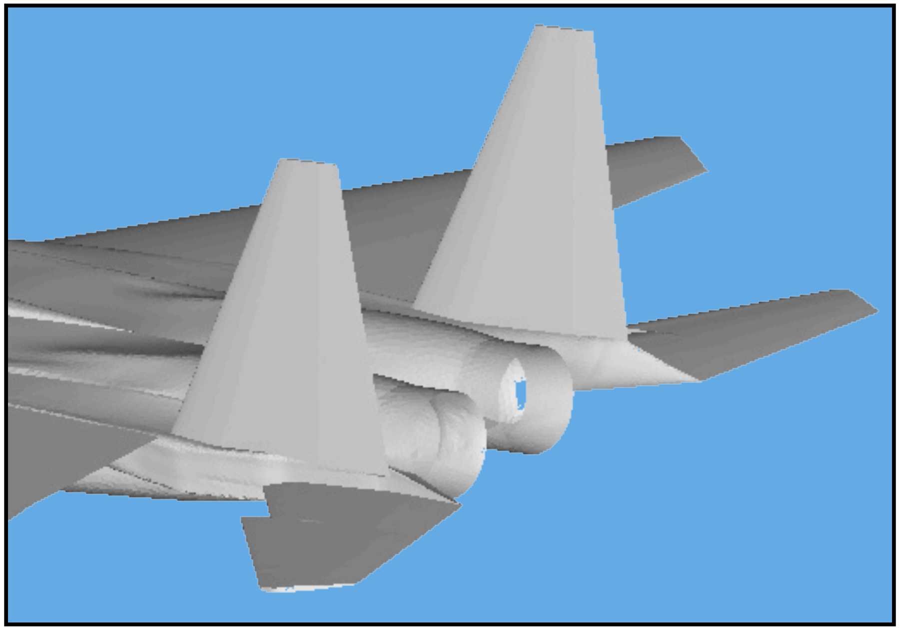
F-15B CFD Geometry

- ***Inlet cowl was rotated down 4º from full up***
  - *Better, but still not correct for actual test points*
- ***Flow through inlet - internal ramps full up position***
  - *not choked, flows fully supersonic*
  - *no spillage*



F-15B CFD Geometry

- Horizontal tail at 0º incidence for all CFD analysis
- Nozzle geometry not correct
- Nozzle flow not correct

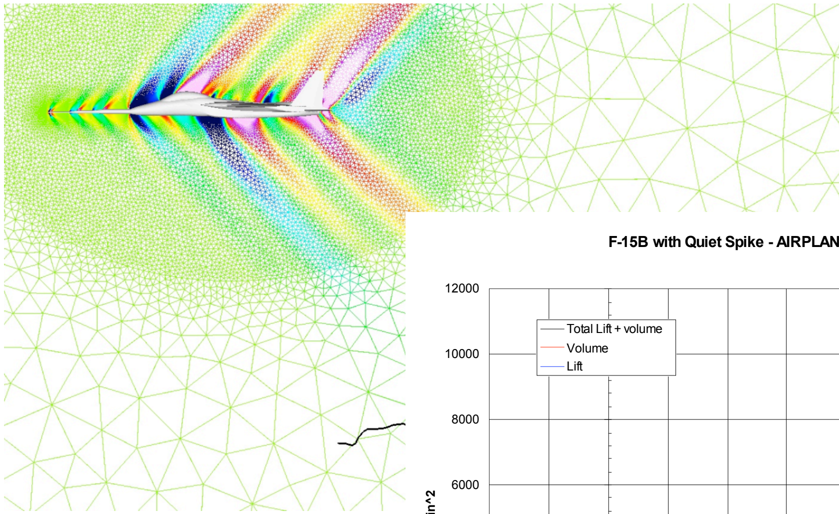


Composite 3-D / Axisymmetric CFD

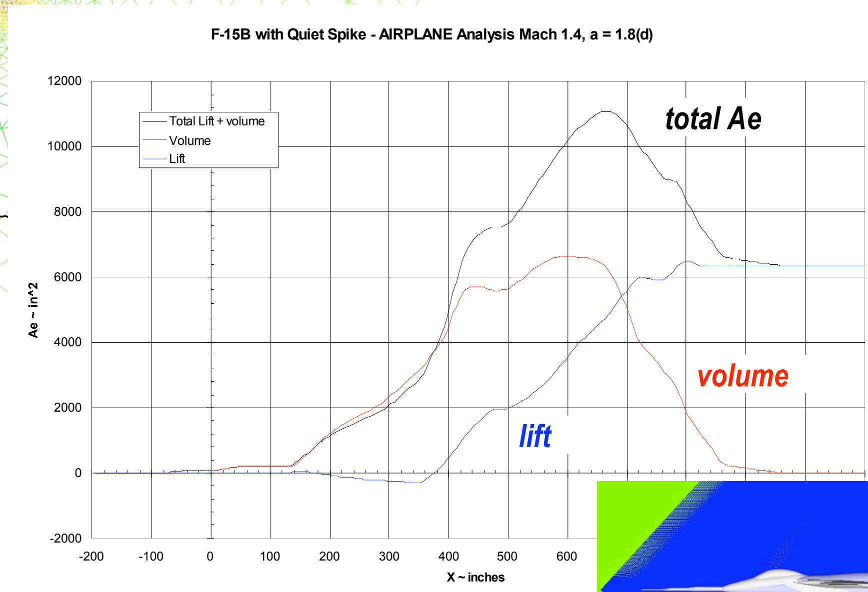
Gulfstream

- **Jameson AIRPLANE code to solve surface pressures (unstructured Euler solver)**
- **Integrate equivalent area distribution from surface pressures and volume**
- **Merge 3-D Quiet Spike geometry with axisymmetric equivalent area representation of the airplane**
- **High resolution OVERFLOW analysis of equivalent area out to 4+ body lengths (280 ft.)**
  - Manually adapted grid
- **Method was developed in 2004 when first evaluating Quiet Spike configurations for possible flight testing**

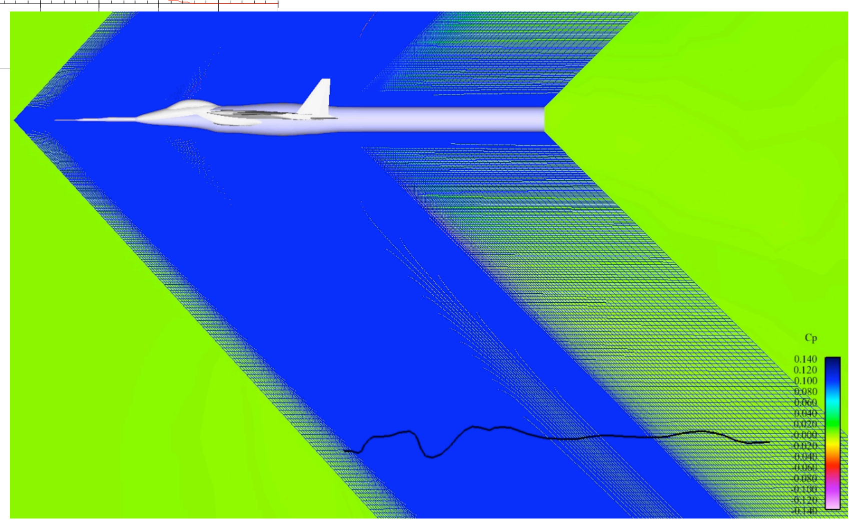
Composite 3-D / Axisymmetric CFD



976,000 grid points, 5.45 million tetrahedral cells
Coarse mesh does not resolve solution out to even the closest probing flight track



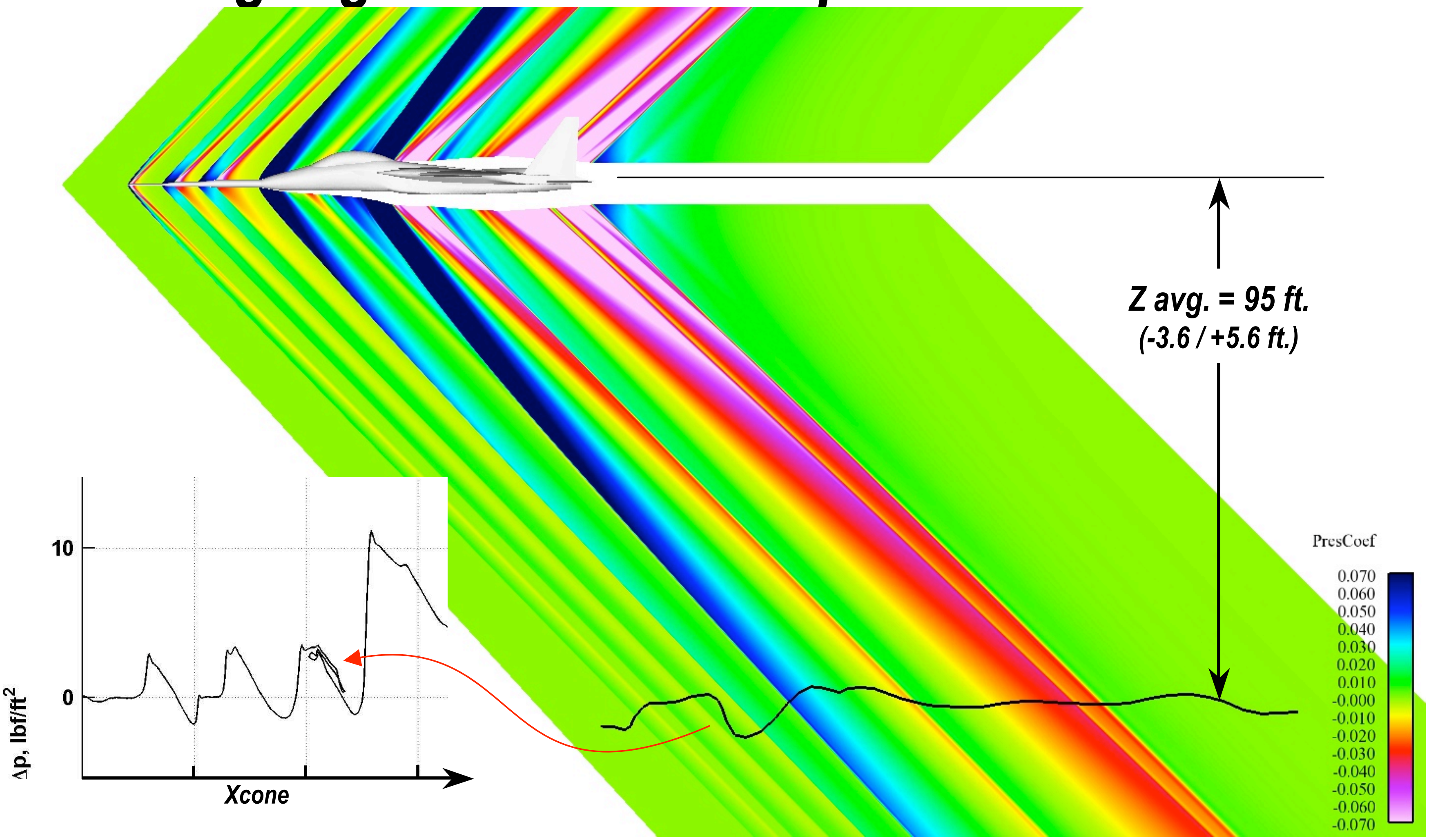
Integrated equivalent area due to lift and volume, uses surface pressure and geometry only



High resolution OVERFLOW model out to 280 ft.
26 million grid points

Composite 3-D / Axisymmetric CFD

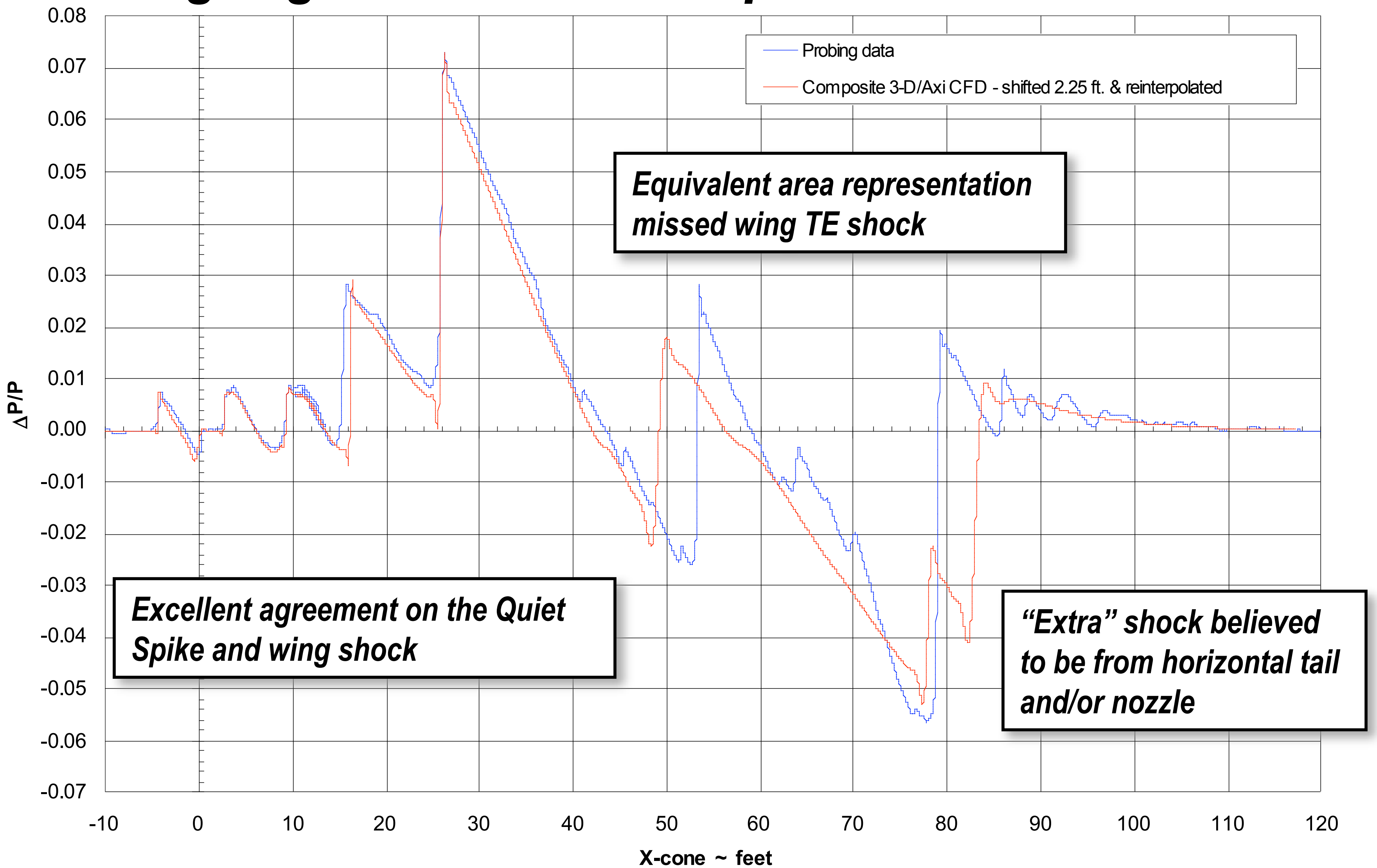
- ***Probing Signature #10 Comparison***



Vertical deviation in flight track collapses when plotted against Xcone

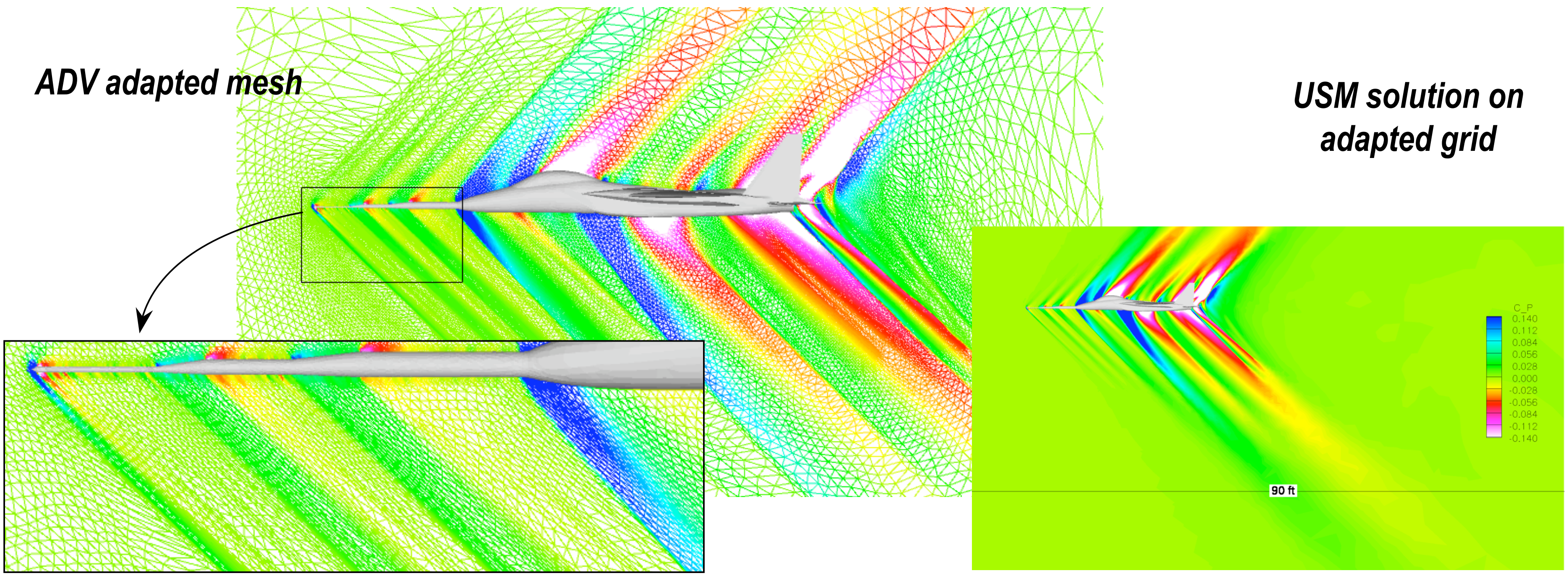
Composite 3-D / Axisymmetric CFD

- **Probing Signature #10 Comparison**



Hybrid Unstructured/Structured CFD

- **USM 3-D unstructured solution out to ~1/3 body length**
  - *Manually positioned grid refinement sources in GridTool*
- **Solution Adapted grid using ADV**
  - *10 adaptation cycles, ADV is a NASA Langley/Dick Campbell code*
  - *INTERP is also used (Steve Massey, NASA Langley Contractor)*

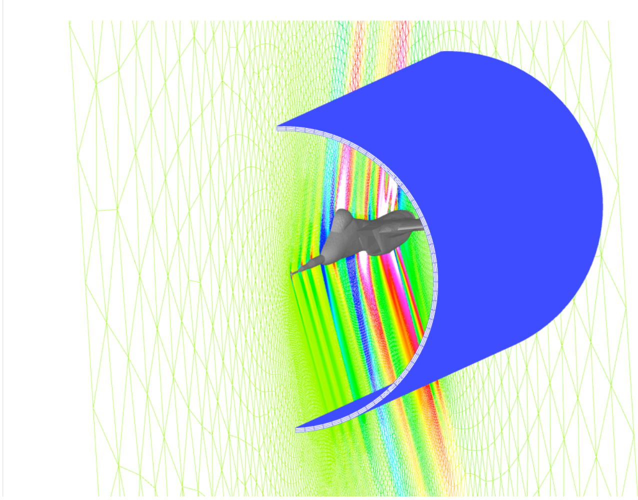


ADV adapted mesh

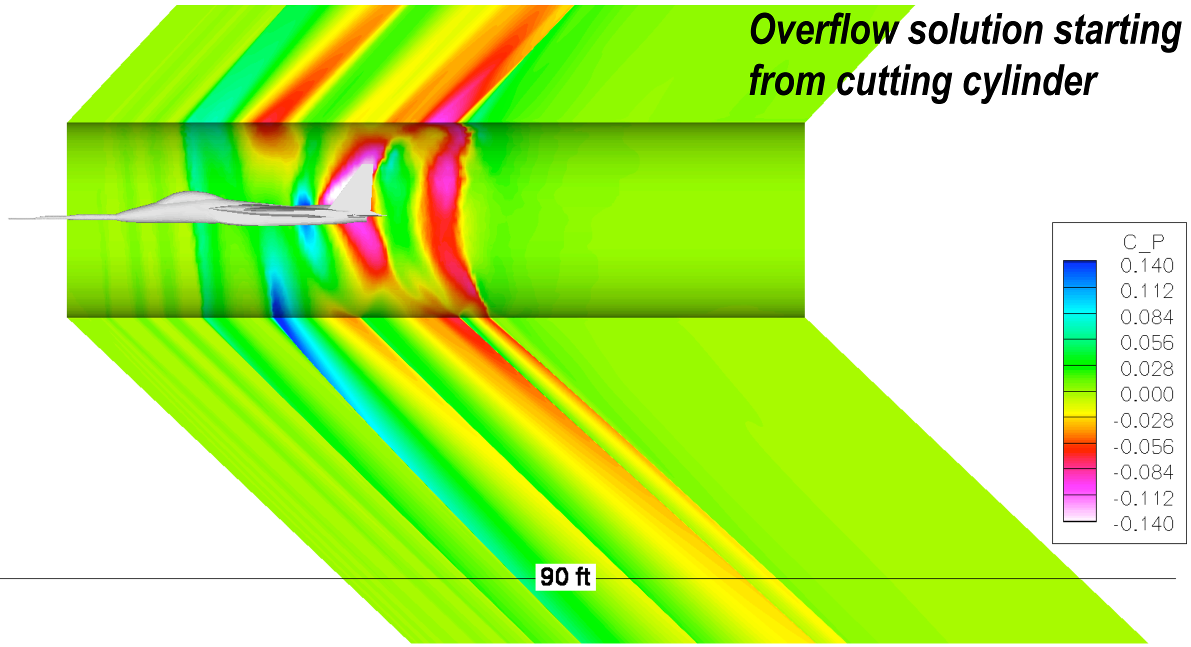
USM solution on adapted grid

Hybrid Unstructured/Structured CFD

- *Interpolate 3-D solution onto structured cutting cylinder*
- *3-D high resolution mid-field with OVERFLOW starting from interpolated solution*
- *Final grid block is similar to Composite 3-D/Axi method but retains all of the 3-D effects on the flow field*



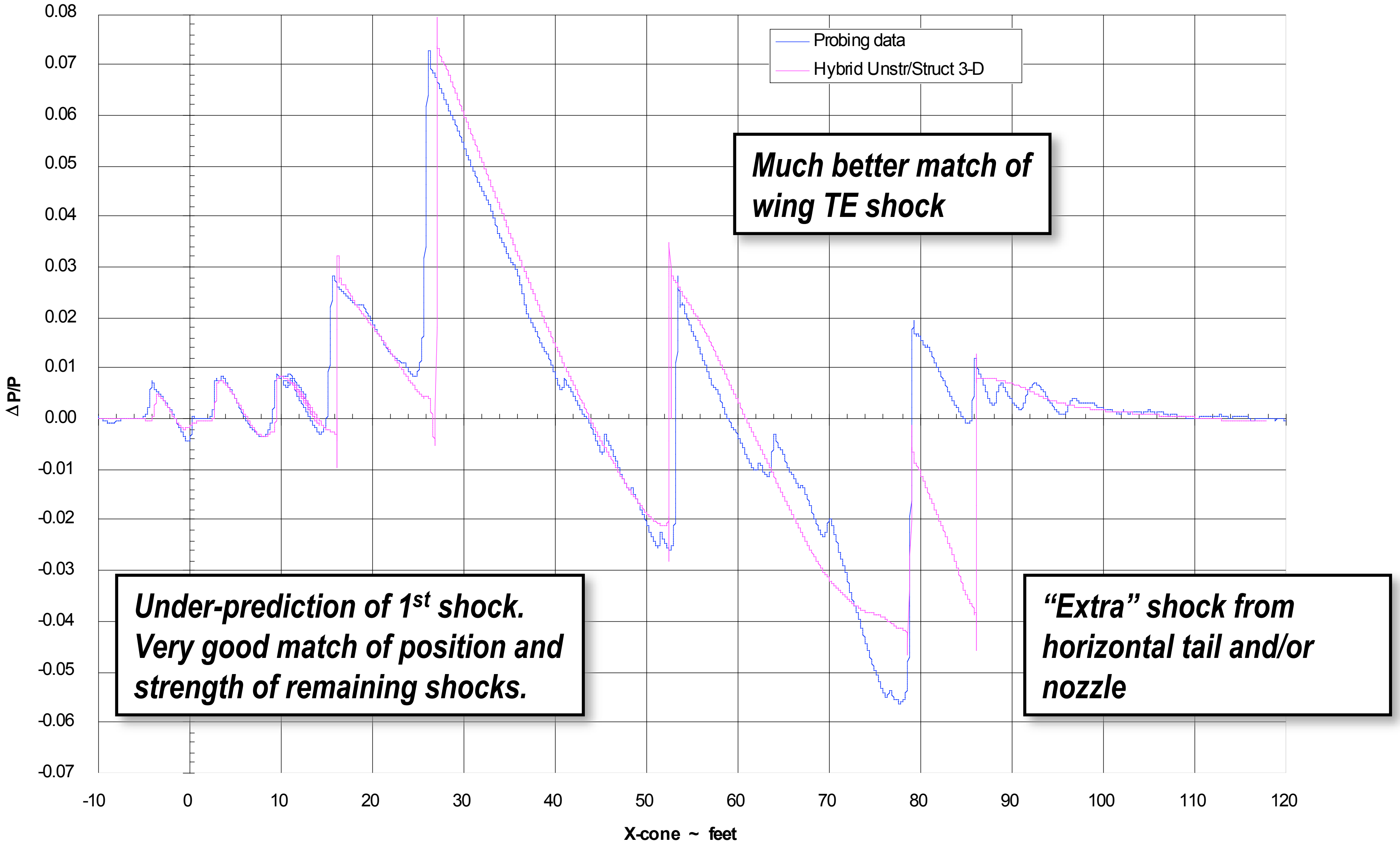
Cylinder is cut outside of wing tip but in close enough to resolve flow field under the airplane



Overflow solution starting from cutting cylinder

Hybrid Unstructured/Structured CFD

- ## Probing Signature #10 Comparison



QuietSpike Near Field Data Summary

- **Airborne Data Gathered**
  - *F-15B #836 airdata calibrated over envelope expansion flights*
  - *GPSsonde weather balloon data*
  - *34 probings recorded one flight (w/ aerial refueling)*
  - *Good distribution of near field distance (79 to 662 ft.) and azimuth (0º to +/- 120º)*
- **Good to Excellent Comparison with CFD**
  - *Quiet Spike shock locations and strengths agree well with both CFD methods*
  - *Slight signature off set consistent with GPS variations and angle of attack uncertainty*
  - *Hybrid 3-D CFD shows better agreement with the rest of the airplane*

QuietSpike Near Field Data Summary

- **Both CFD Methods Have Their Place**
  - *Hybrid 3-D shows better agreement but is more labor and computationally intensive*
  - *Composite 3-D/Axi- is a relatively fast procedure (labor and computational) that would be well suited for evaluating a range of configuration variations*
- **Further Effort**
  - *Quiet Spike near field probing data provides an excellent data set of CFD methods development and validation*
  - *Data will be used to continue refinement and automation of the CFD grid and solution procedures*