Fan Rig Noise Spectral Correction for NASA 9'x15' Low-Speed Wind Tunnel

Nick Schifer and Cliff Brown
NASA GRC
Acoustics Technical Working Group

ABSTRACT

Aircraft engine noise research and development depends on the ability to study and predict the noise created by each engine component in isolation. Fan noise testing, however, requires a significant support system including a drive mechanism to turn the fan, a device to smooth the flow into the fan, and a stand to raise the fan off the ground each of which has the potential to create its own noise. A methodology was therefore developed to improve the data quality for the 9x15 Low Speed Wind Tunnel (LSWT) at the NASA Glenn Research Center that identifies three noise sources: fan noise, jet noise, and rig noise. The jet noise and rig noise was then measured by mounting a scale model of the 9x15 LSWT setup in a jet rig to simulate everything except the rotating machinery that characterizes fan noise. The data showed that the spectra measured in the LSWT has a strong rig noise component at frequencies as high as 3 kHz depending on the fan and speed. The jet noise was determined to be significantly lower than the rig noise. A mathematical model for the rig noise was then developed using a multi-dimensional least squares fit to the rig noise data. This allows the rig noise to be subtracted or removed, depending on the amplitude of the rig noise relative to the fan noise, at any given frequency, observer angle, or nozzle pressure ratio. The impact of isolating the fan noise with this method on spectra, overall power level (OAPWL), and Effective Perceived Noise Level (EPNL) is studied.

National Aeronautics and Space Administration

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Outline

- Key definitions
- Motivation
- LSWT and Model comparisons
- Characterizing the rig noise
- Verifying the work
- Final conclusions

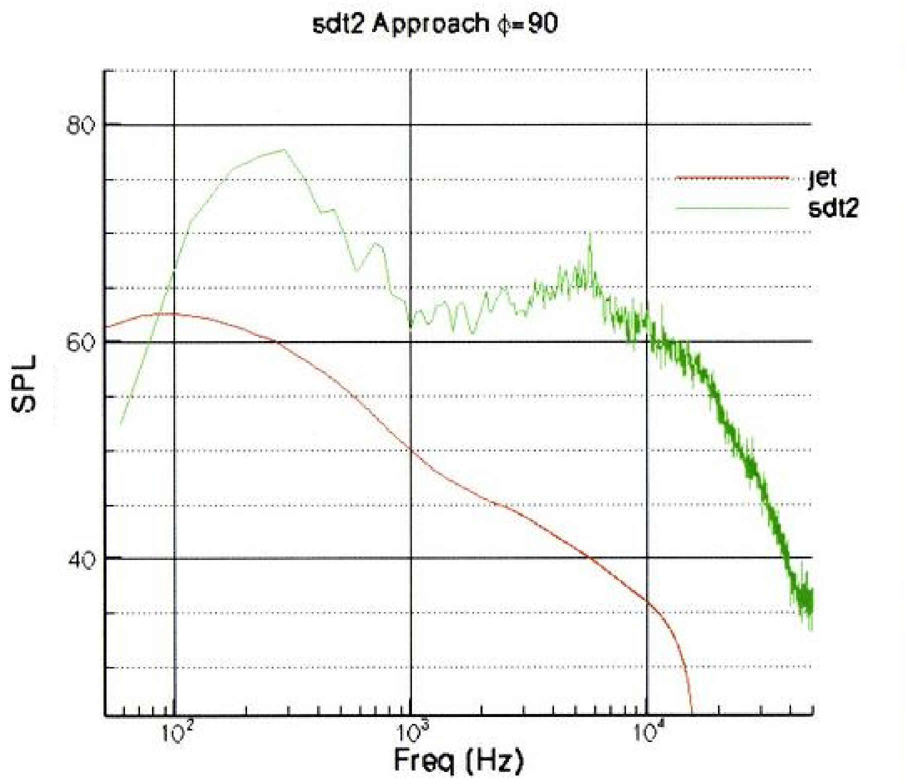
Key Definitions

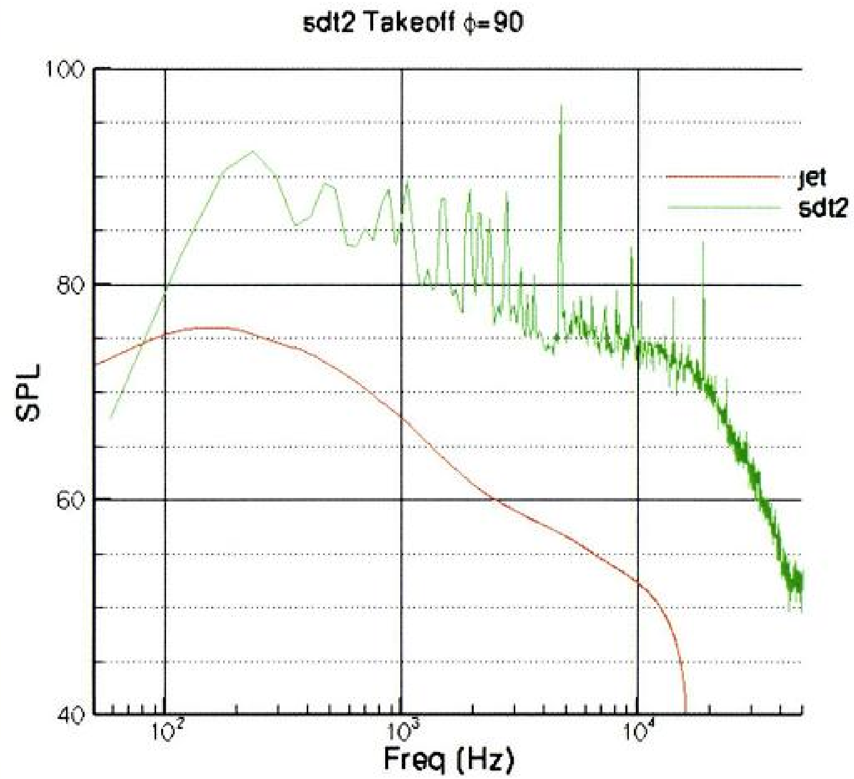
- Fan noise - the noise generated inside the bypass duct by the rotating fan and the flow interactions with the stator vanes

- Jet noise - noise created by the fan flow exhausting from the bypass nozzle and interacting with the surrounding air

- Rig noise - all other noise sources (i.e. flow interactions with the drive rig support system, etc.)

Spectra Comparison Illustrates Question Regarding 9x15 Fan Data

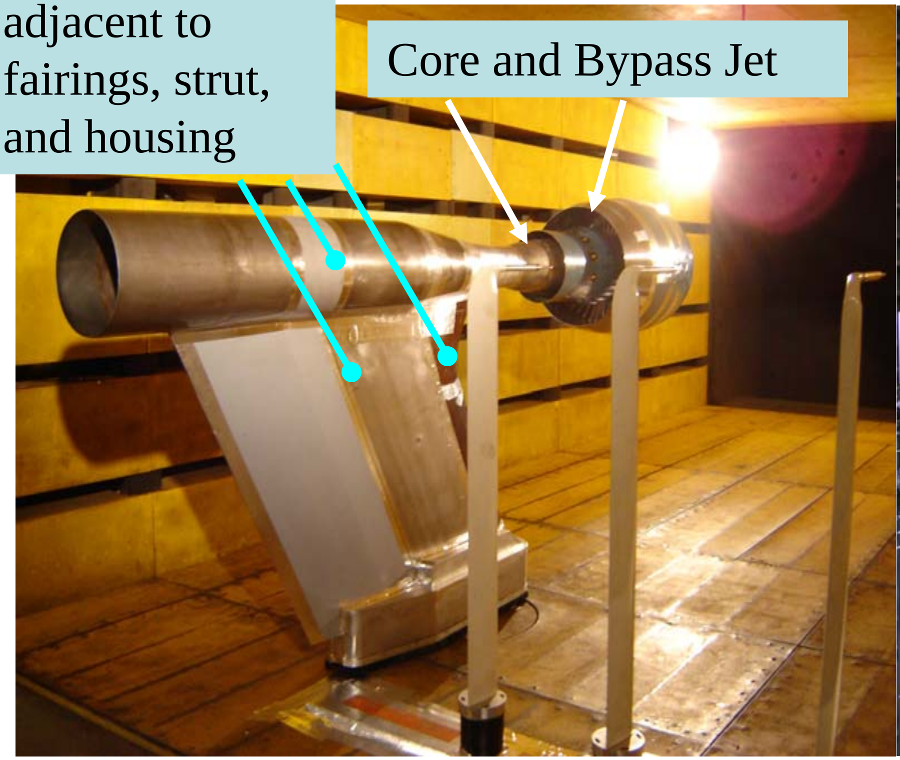




- Near 1kHz and below, data looks like jet noise +15dB. Why 15dB high?
- Suspect external flow interaction with rig amplifies “jet” noise.
- 9x15 as measured noise data contains fan noise, jet noise, and rig noise
- May suggest reprocessing of measured noise data to remove added rig noise, jet noise, or both.

Test Rig and Model Comparison

9x15 LSWT



- Fan/Nacelle Tested using air driven turbine to power fans
- 9x15 noise measurements include fan plus bypass nozzle jet contribution (plus core if used)

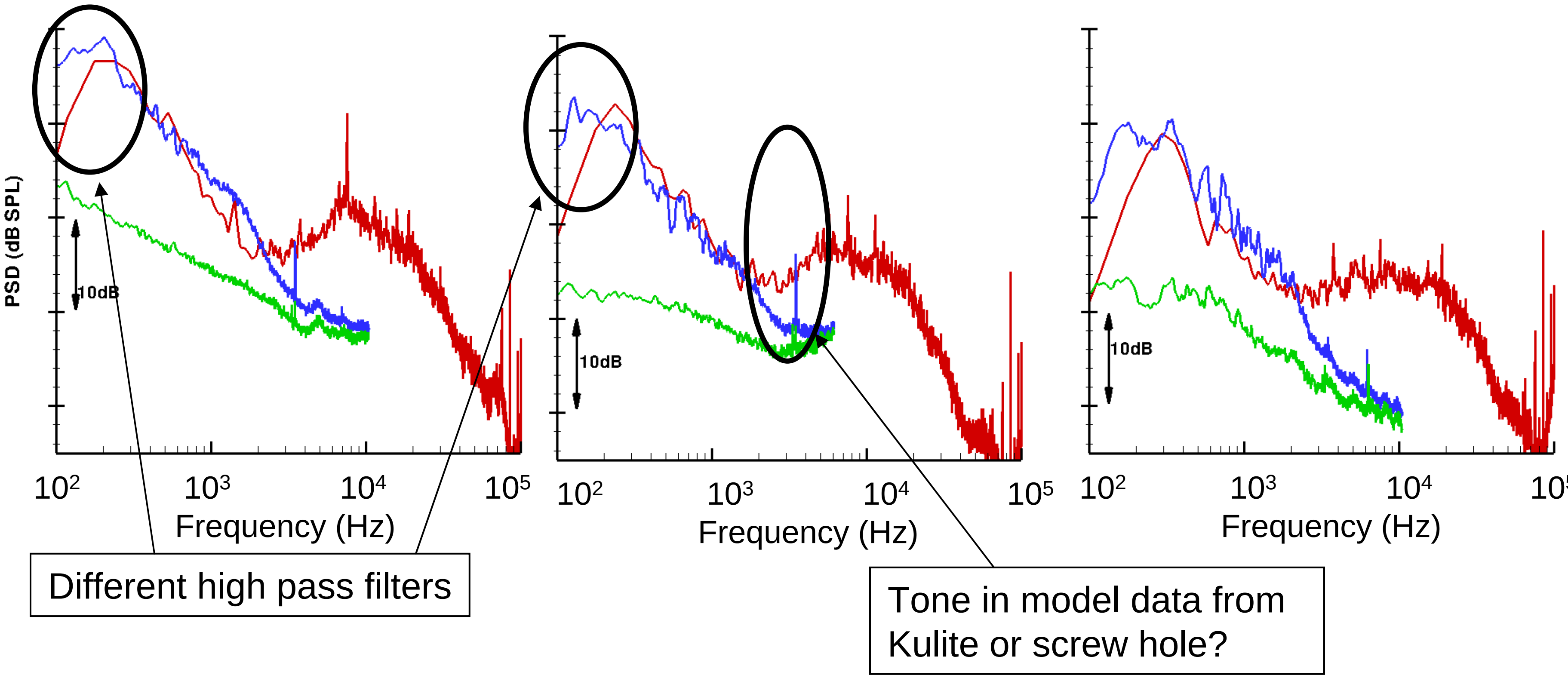
Nozzle Acoustic Test Rig (NATR)

- 0.45 scale UHB Drive Rig Model tested with cone at turbine exit to eliminate shedding noise
- Microphone positions duplicate some 9x15 tunnel traverse stop locations

SDT2 Cutback Condition

$NPR_f \sim 1.28$

Aft (~130º) | Broadside (~90º) | Inlet (~40º)



- Good agreement below ~2 kHz between wind tunnel and model data.
- Jet alone data well below wind tunnel and model data.

ADP and QHSF2 Comparisons

Red = Aft

Blue = Broadside

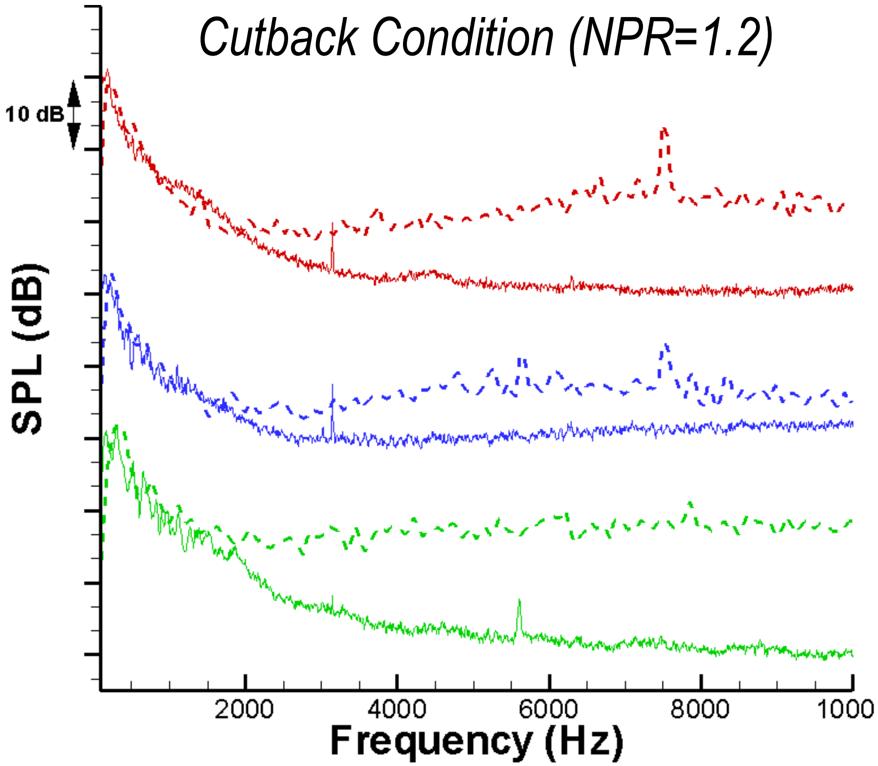
Green = Inlet

Dashed Line (- - - - - -) = As Measured Noise

Solid Line (————————) = Rig Noise

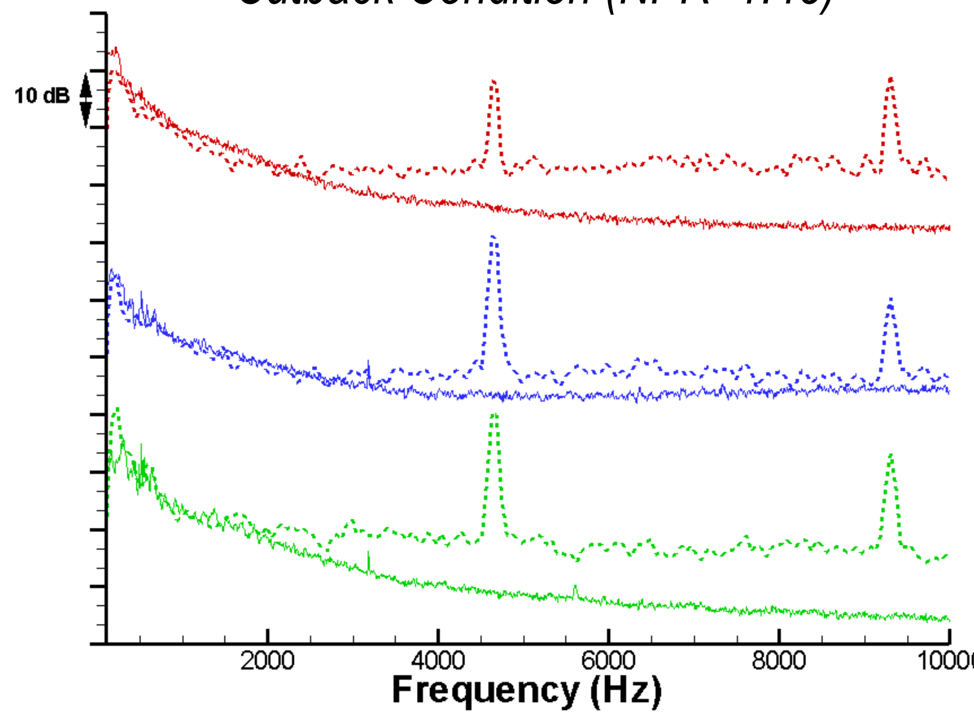
ADP Fan Model vs. Measured Rig Noise

Cutback Condition (NPR=1.2)



QHSF2 Fan Model vs. Measured Rig Noise

Cutback Condition (NPR=1.45)



Experimental Conclusions and Next Steps

Conclusions*

- Model successfully reproduced the rig noise observed in the 9x15 noise spectra at low frequencies
- Data from the drive rig model allows the rig noise to be identified and/or removed from the 9x15 noise data

Next Steps

- Develop a universal model to match the measured rig noise data to fan specific nozzle pressure ratios
- Apply model to correct noise data measured in the 9x15 LSWT

*from Cliff Brown's Spring 2007 Technical Working Group Presentation

Our Approach

- Rig noise is universal to all fans tested in 9x15 LSWT
- Initial scale model validation required…
  - Interpolations in angle and frequency
  - Scale adjustments for the various fan nozzle areas
- One alternative: lookup tables
  - Perform linear or higher order interpolations
  - Very cumbersome
- Second alternative: Define the rig noise data with a generalized equation or set of equations
  - Internalizes interpolations

Model Coverage

- Model covers full range of expected test conditions
  - Nozzle exit conditions: 1.05-1.50
  - Angles: 30^o-131^o
  - Frequencies: 250-5000 Hz
    - Larger frequency range = reduction in accuracy of fit
    - Smaller frequency range = reduces utility of fit

    - Lower limit: tunnel not anechoic below 250 Hz
    - Upper limit: data indicate fan noise dominates for frequencies above 4 to 5 kHz

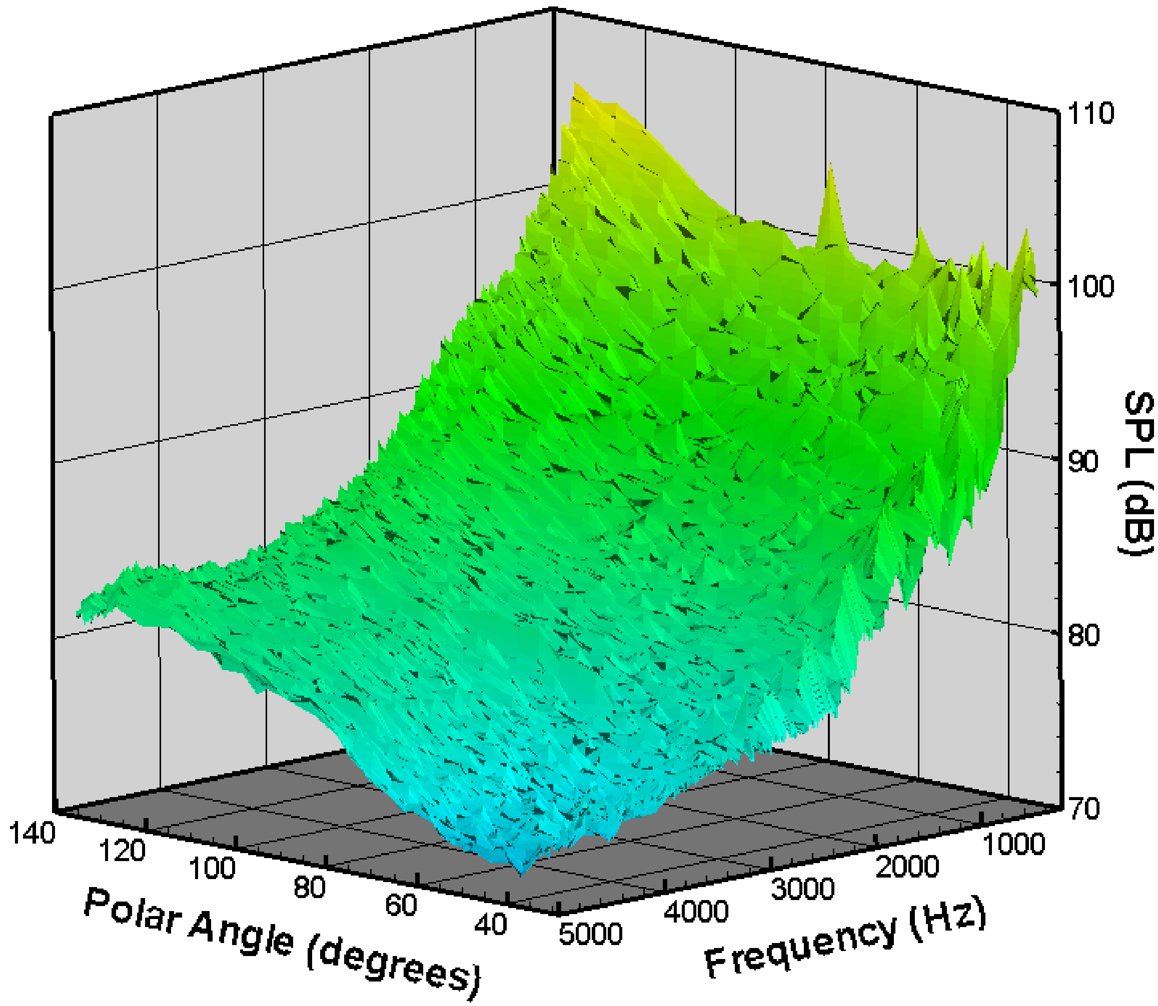
General Surface

The measured rig noise processed to full LSWT scale and to a one-foot lossless condition for all angles and frequencies measured at a single nozzle pressure ratio.

Angle: 30º-131º

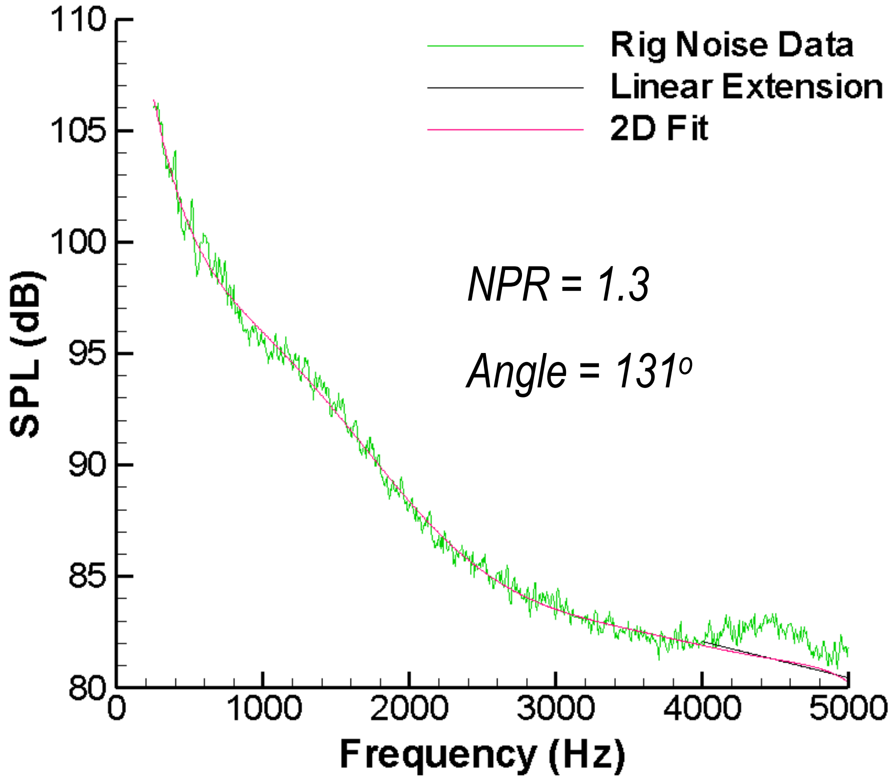
Frequency: 250- 5000 Hz

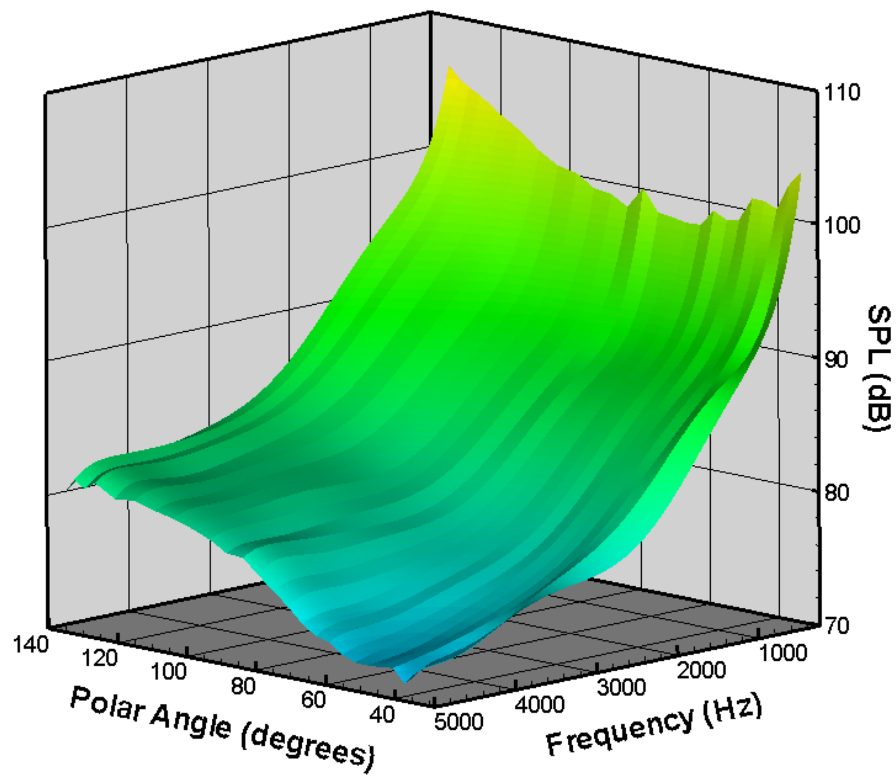
NPR: 1.3



Data Simplification

- Generate a smoother surface by first fitting in 2D for all angles and nozzle conditions



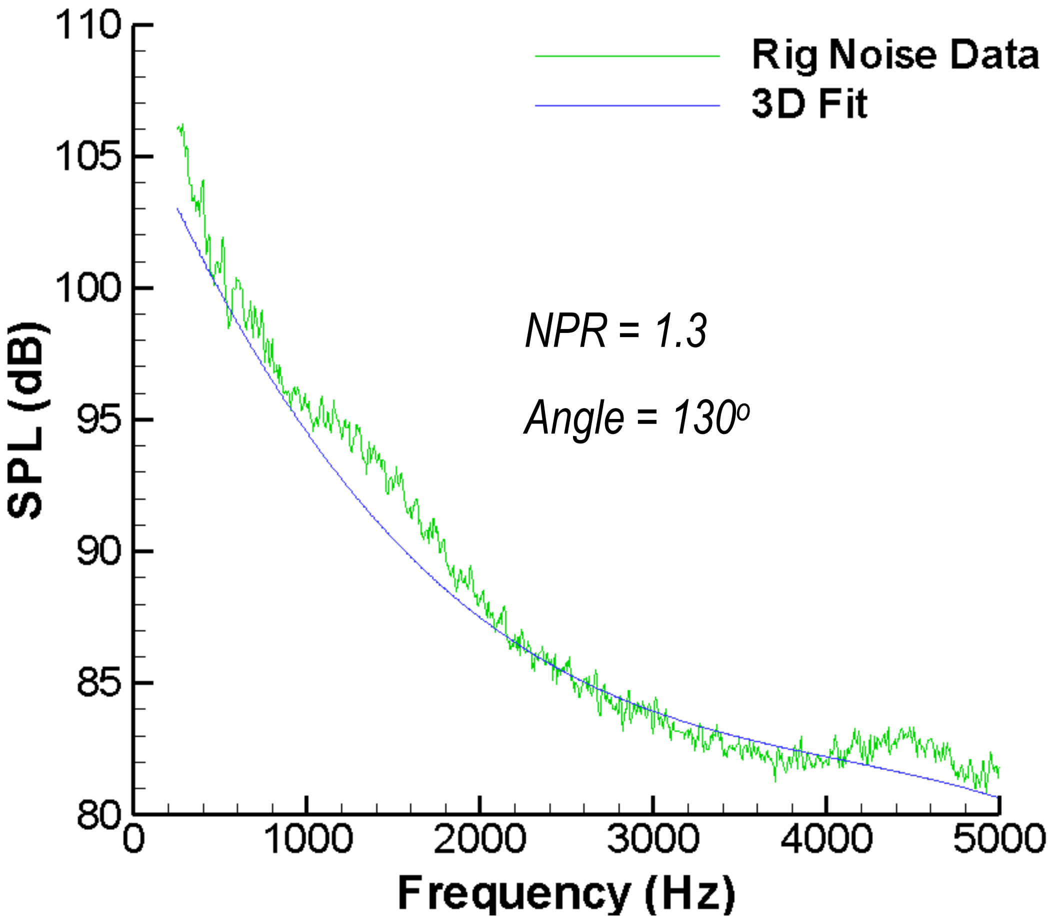


- Fit across frequency range of 250-5000 Hz
- Forced roll off at higher frequencies

3D Fitting Equation

$$SPL\ (dB) = a + b\theta + c\omega + d\theta^2 + e\omega^2 + f\theta^3 + g\omega^3$$

- *letters 'a' through 'g' are the defining coefficients*
- *'θ' is the polar angle (in degrees)*
- *'ω' is the frequency (in Hz)*

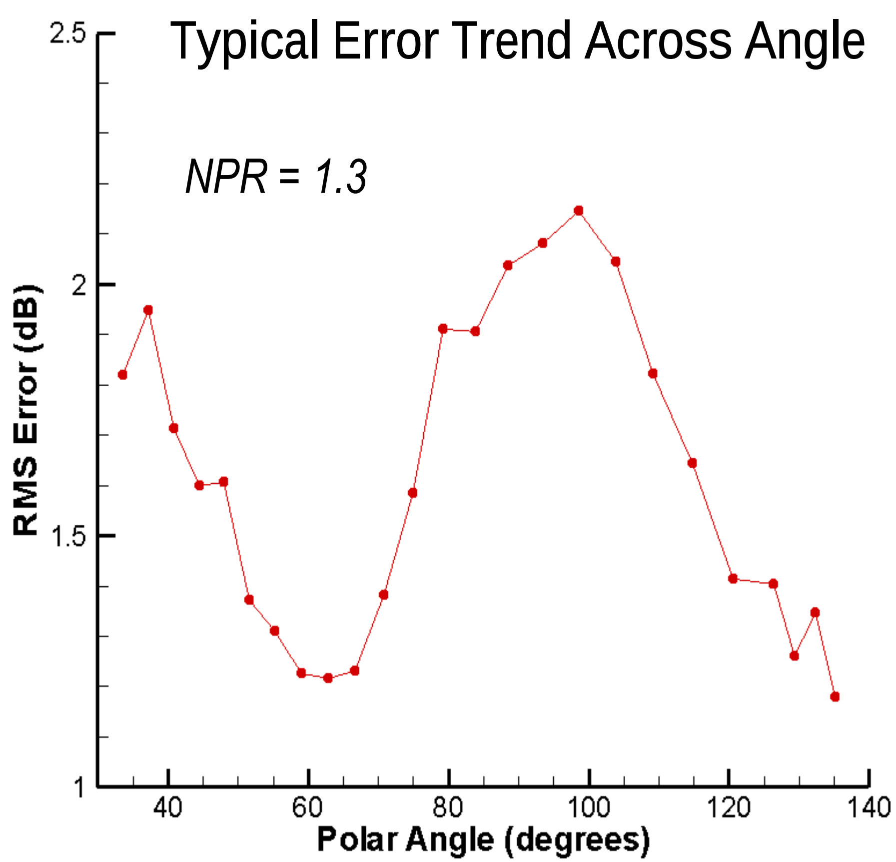


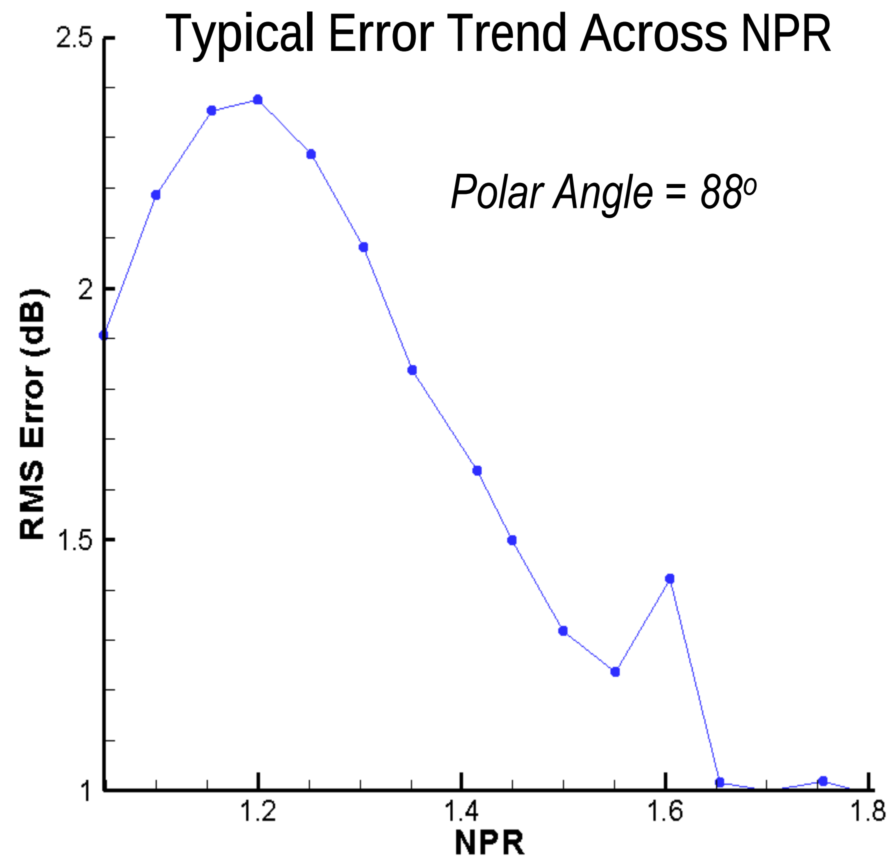
- 16 sets of defining coefficients, one for each NPR tested
- Linear interpolation applied across NPR
- Coefficients found using the method of least squares

Error Analysis

- Comparison of the mathematical model to the test model data from which it was derived
- RMS error calculated based on SPL across the frequency range of 250-5000 Hz for each nozzle condition and angle combination
- Goal: Keep the RMS error less than 3 dB

Error Analysis Results



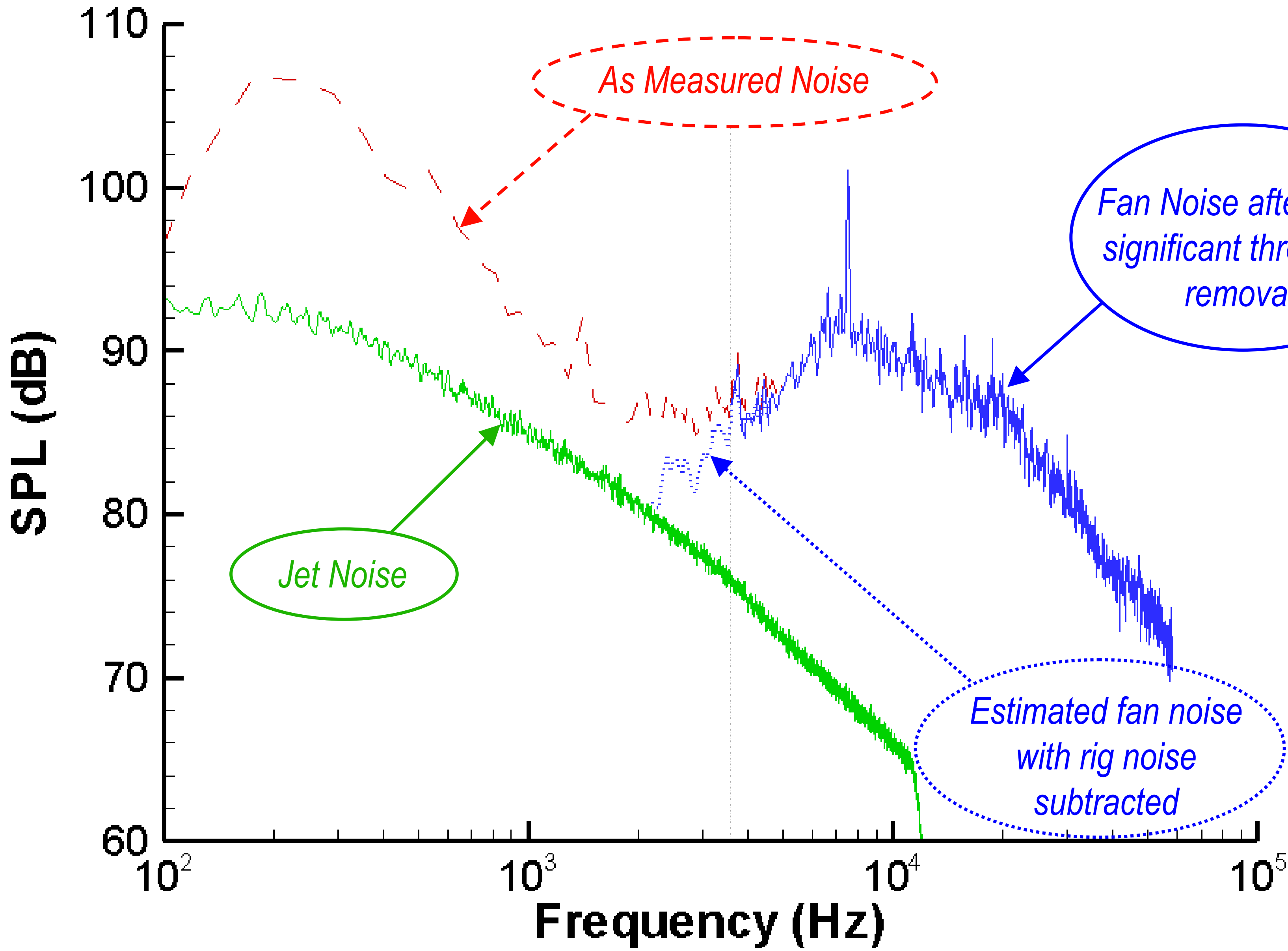


RMS errors global to all test conditions

Max RMS error: 2.78 dB

Min RMS error: 0.74 dB

Original Data vs. Reprocessed Data



OAPWL and EPNL Calculations

- Acoustic data traditionally considered valid between 1kHz and 50 kHz
- Analysis of the rig noise proves that the 1 kHz lower frequency was too low

Fan	Condition	OAPWL 1-50 kHz	OAPWL “Fan”	∆ OAPWL	EPNL 1-50 kHz	EPNL "Fan"	∆ EPNL
SDT R4	Approach	117.79	116.78	1.01	73.65	72.87	0.78
SDT R4	Cutback	129.43	129.14	0.29	85.80	84.33	1.47
SDT R4	Takeoff	137.40	134.62	2.78	93.57	91.88	1.69
ADP F1	Approach	118.86	118.60	0.26	75.27	74.70	0.57
ADP F1	Cutback	124.28	123.99	0.29	80.57	79.55	1.02
ADP F1	Takeoff	130.39	130.20	0.19	87.24	86.42	0.82
QHSF2	Approach	129.27	128.99	0.25	67.77	66.53	1.24
QHSF2	Cutback	136.28	135.91	0.37	77.81	74.07	3.74
QHSF2	Takeoff	136.72	134.87	1.85	77.16	67.20	9.96

Conclusions

- Extraneous noise source (rig noise) was identified and an experimental model was developed
- Rig noise data was characterized by a mathematical model and removed from the wind tunnel (as measured) data
- Rig noise proved to be a significant part of the total noise measured in the LSWT and it's removal had significant impacts on OAPWL and EPNL values

Future Work

- Further investigation into rig noise data collected at NPRs of 1.5 and greater
- A technical paper is being written and will be presented at the ASME Turbo Expo 2008

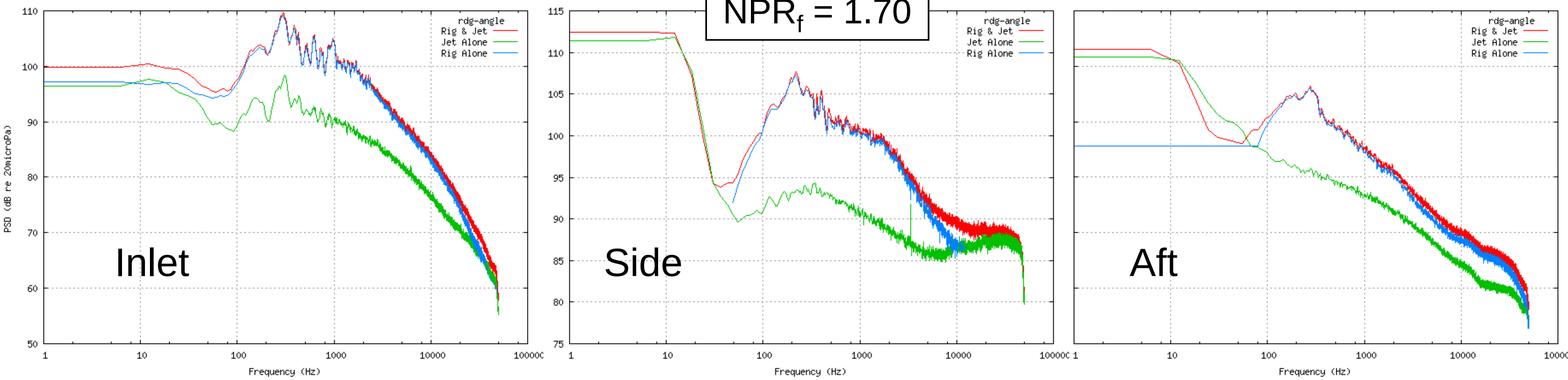
Extra Slides

Drive Rig and Jet Noise Separation

Want to isolate contributions from rig scrubbing noise and jet noise separately

"Rig & Jet" noise (measured in AAPL)
Jet Alone noise (measured in AAPL)
Rig Alone noise ("Rig & Jet" - "Jet Alone" w/ 3dB threshold)

$NPR_f = 1.70$



- "Rig & Jet" noise is nearly identical to "Rig Alone" noise
- "Rig Alone" noise is not useful as a stand alone model for data processing purposes
- Removing "Jet Alone" noise will not significantly change the fan noise spectra

The Coefficients

NPR	a	b	c	d	e	f	g
1.0488	9.015E+01	-6.929E-01	-1.171E-02	9.296E-03	4.077E-06	-3.240E-05	-4.630E-10
1.0998	1.037E+02	-7.481E-01	-2.208E-02	1.007E-02	7.120E-06	-3.582E-05	-7.392E-10
1.1538	1.037E+02	-5.079E-01	-2.252E-02	7.086E-03	6.592E-06	-2.483E-05	-6.409E-10
1.2005	1.068E+02	-4.892E-01	-1.959E-02	6.472E-03	5.227E-06	-2.199E-05	-4.809E-10
1.2520	1.065E+02	-3.823E-01	-1.711E-02	4.967E-03	4.090E-06	-1.604E-05	-3.456E-10
1.3036	1.073E+02	-3.299E-01	-1.531E-02	4.166E-03	3.398E-06	-1.281E-05	-2.759E-10
1.3516	1.082E+02	-3.026E-01	-1.380E-02	3.673E-03	2.851E-06	-1.063E-05	-2.208E-10
1.4158	1.153E+02	-4.569E-01	-1.299E-02	5.126E-03	2.651E-06	-1.518E-05	-2.084E-10
1.4492	1.158E+02	-4.293E-01	-1.265E-02	4.742E-03	2.575E-06	-1.369E-05	-2.039E-10
1.4996	1.159E+02	-3.568E-01	-1.141E-02	3.759E-03	2.295E-06	-1.016E-05	-1.871E-10
1.5517	1.160E+02	-2.999E-01	-9.369E-03	3.139E-03	1.734E-06	-8.847E-06	-1.366E-10
1.6047	1.169E+02	-3.104E-01	-7.446E-03	3.441E-03	1.317E-06	-1.116E-05	-1.066E-10
1.6538	1.169E+02	-3.466E-01	-6.778E-03	3.906E-03	1.081E-06	-1.240E-05	-7.898E-11
1.7018	1.156E+02	-3.385E-01	-6.120E-03	3.819E-03	8.902E-07	-1.148E-05	-5.993E-11
1.7553	1.161E+02	-3.894E-01	-5.401E-03	4.553E-03	8.374E-07	-1.422E-05	-6.769E-11
1.8071	1.165E+02	-3.921E-01	-4.569E-03	4.618E-03	7.164E-07	-1.465E-05	-6.340E-11