



# Reanalysis of subjective crackle ratings using a logistic curve fit



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8 December, 2022, Nashville, TN  
183<sup>rd</sup> Meeting of the Acoustical Society of America, 4aNS6  
4aNS: Jet and Launch Vehicle Noise I (Hybrid Session)



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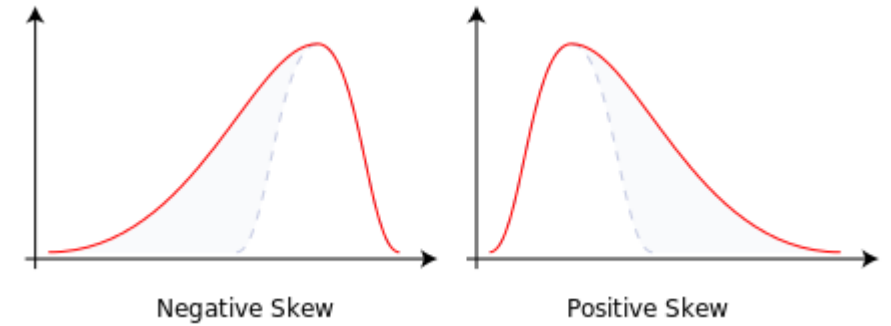
# Crackle background



Without

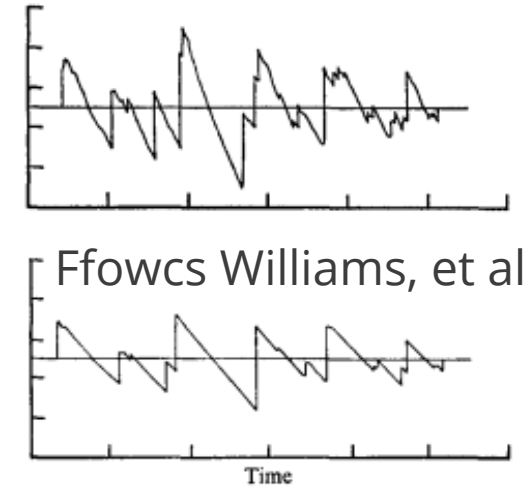


With



Sound quality associated with high-performance jets

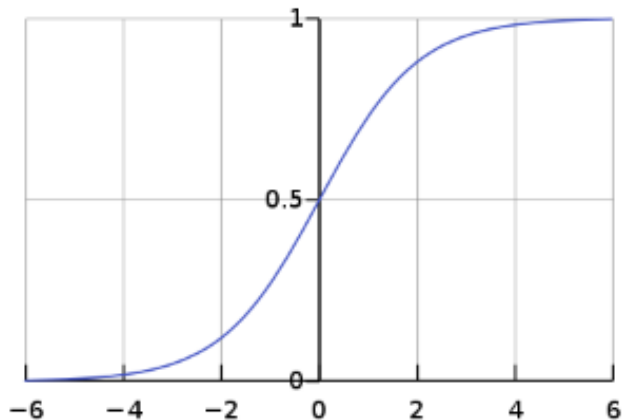
- Most poetic description of sound quality given by Ffowcs-Williams
- Crackle quantification controversial: Skewness v. Derivative skewness
  - $Sk\{p\}$  or  $Sk\{dp/dt\}$ ?
  - Skewness ( $Sk$ ) describes how asymmetrical a distribution is
  - Ultimately “resolved” by subject test
  - **Pressure skewness ( $Sk\{p\}$ )** does not affect crackle perception
  - **Pressure derivative skewness ( $Sk\{dp/dt\}$ )** does affect crackle perception
- Qualitatively related to the presence of shocks and their contrast with intervening periods of relative quiet
- Results from waveform steepening – at the source, or while propagating



# Gee et al study



- 15 waveforms varying in  $Sk\{p\}$ ,  $Sk\{dp/dt\}$ ;  $Sk\{p\}$ , non-significant
- 31 subjects compared 15 jet noise waveforms using category subdivision scaling
- Data points captured using MATLAB user function Grabit
- Gee *et al.* used linear fit to data applied over sample range
- Logistic function fit!

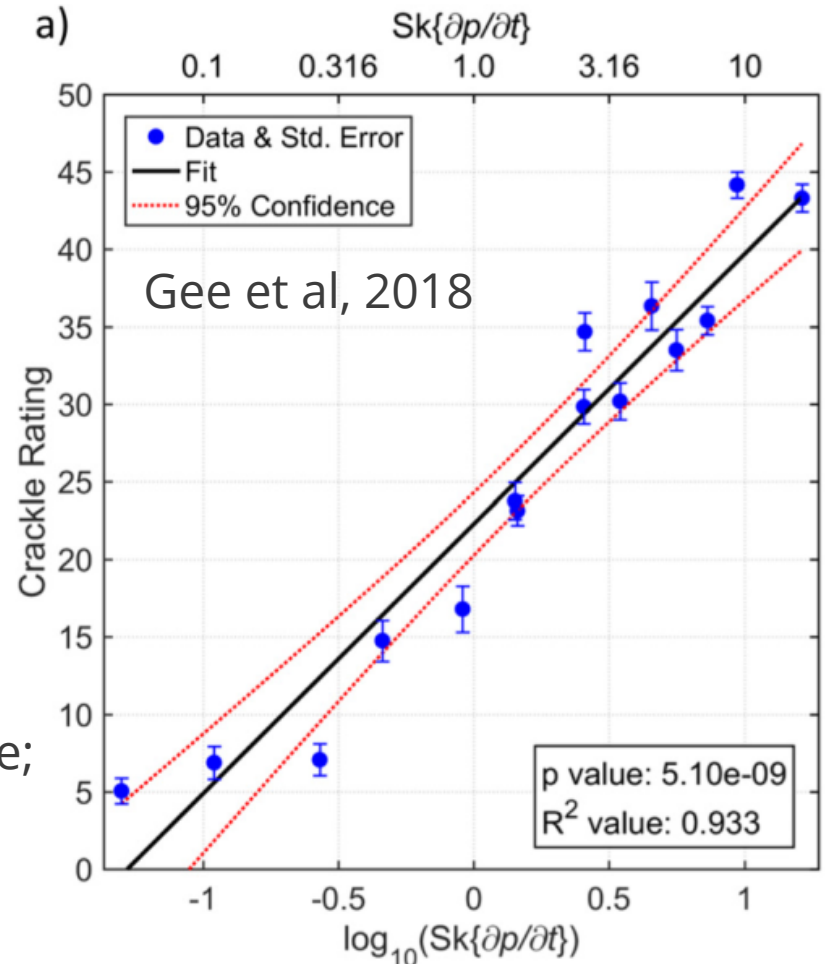


Intense  
crackle

Continuous  
crackle

Sporadic  
intermittent  
crackle  
Rough noise;  
no crackle

Smooth noise;  
no crackle



# Linear vs. logistic curve fit

$$f(x) = ax + b$$

Linear fit ( $Li\{\cdot\}$ )

- As  $Sk\left\{\frac{\partial p}{\partial t}\right\} \rightarrow 0$ ,  $Li\left\{\log\left\{Sk\left\{\frac{\partial p}{\partial t}\right\}\right\}\right\} \rightarrow -\infty$
- As  $Sk\left\{\frac{\partial p}{\partial t}\right\} \rightarrow \infty^+$ ,  $Li\left\{\log\left\{Sk\left\{\frac{\partial p}{\partial t}\right\}\right\}\right\} \rightarrow \infty$
- **Asymptotic behavior inappropriate**
- Two parameters slope,  $a$ , and intercept,  $b$

$$f(x) = \frac{L_{upper}}{1 + e^{-k(x-x_0)}} + L_{lower}$$

Logistic curve fit ( $Lo\{\cdot\}$ )

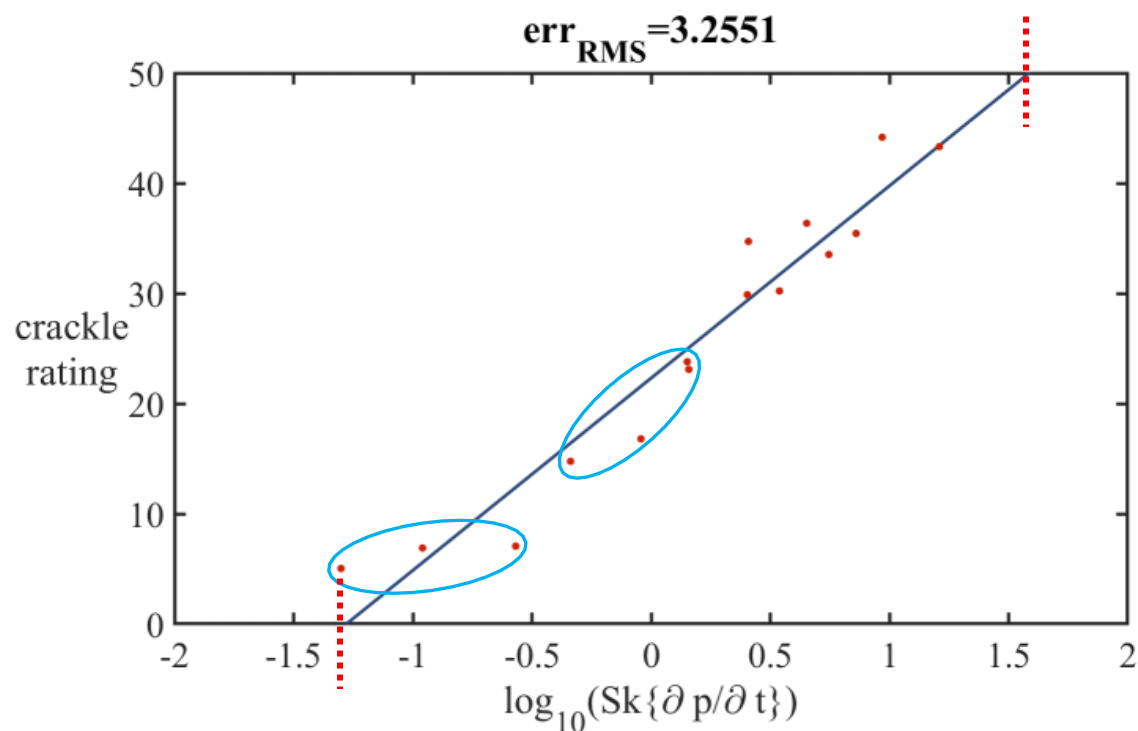
- As  $Sk\left\{\frac{\partial p}{\partial t}\right\} \rightarrow 0$ ,  $Lo\left\{\log\left\{Sk\left\{\frac{\partial p}{\partial t}\right\}\right\}\right\} \rightarrow L_{lower} = 0$
- As  $Sk\left\{\frac{\partial p}{\partial t}\right\} \rightarrow \infty^+$ ,  $Lo\left\{\log\left\{Sk\left\{\frac{\partial p}{\partial t}\right\}\right\}\right\} \rightarrow L_{upper} = 50$
- **Asymptotic behavior appropriate**
- Two parameters (center,  $x_0$ , and slope,  $k$ ) remain



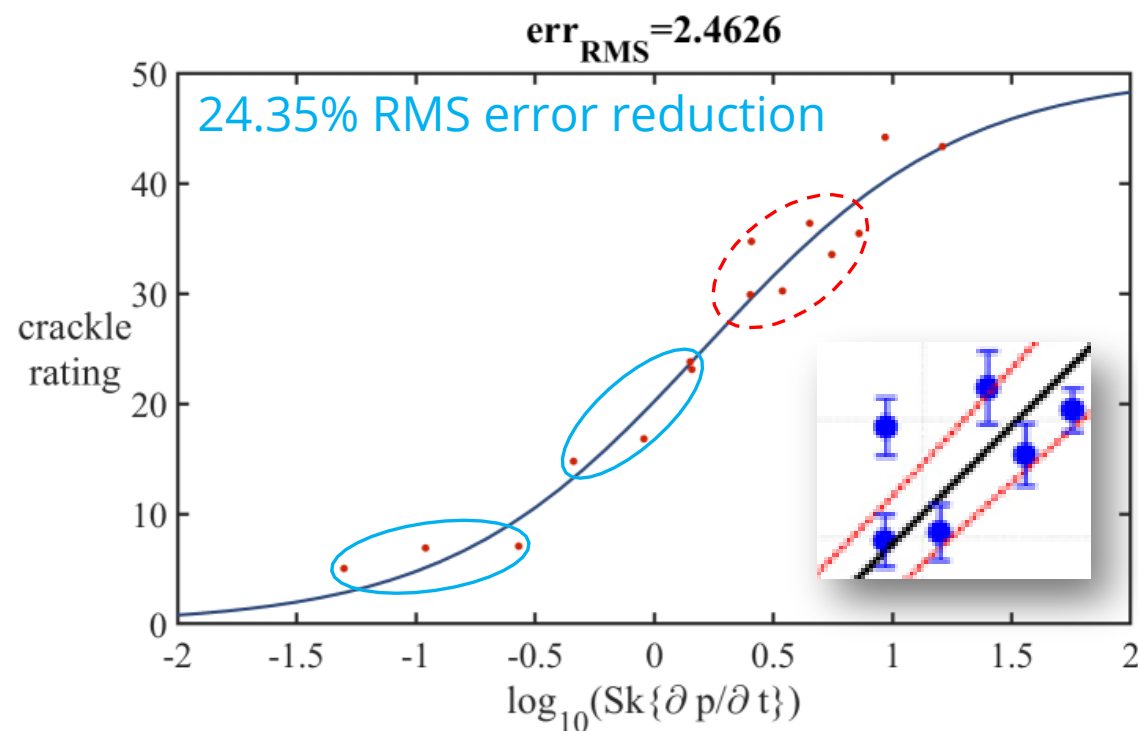
# Linear vs. logistic curve fits



Linear



Logistic



## Unresolved question...



*Is the best measure of the physical processes that lead to crackle the same as the best measure of crackle perception?*

- **Derivative skewness identifies crackle-producing physical processes** including nonlinear steepening of waveforms
- Significant nonmonotonicity in perceptual results is a serious shortcoming
- Suggests that what the physical metric measures and what subjects experience are similar, but imprecisely aligned
- Sound quality metrics may be more well-suited to assess the perceptual quality, and data should be reanalyzed using metrics

# Sound quality-based analysis



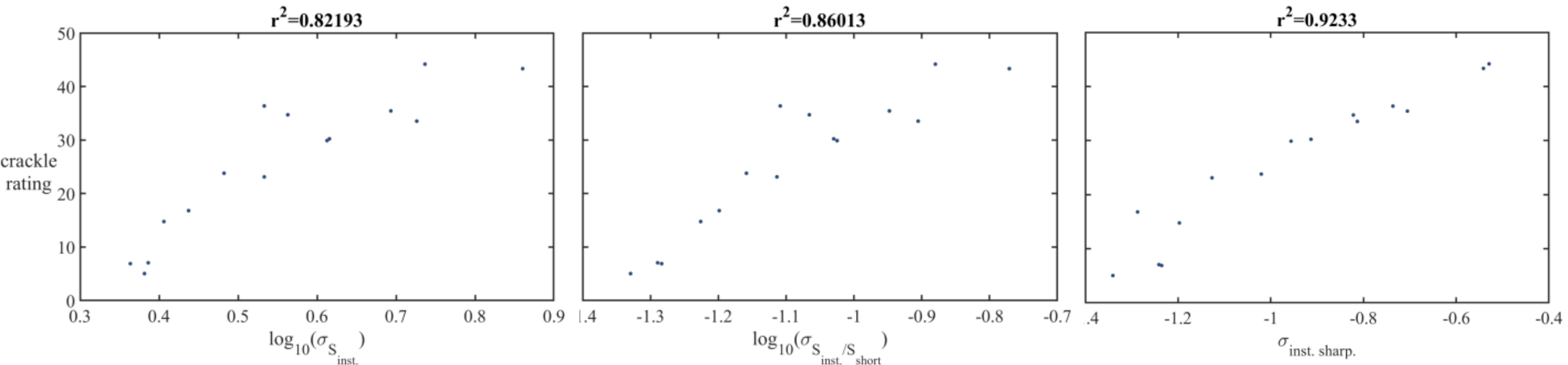
- Prior association shown between crackling sound quality and distributions of sharpness and loudness
- Sound files from subject test were retained enabling a reanalysis using metrics
- Sound calibrated to have a median loudness within 1/100 of a sone of 40 sone
- Transients were cut off
- Sound quality metrics (time-varying) were calculated
- Measures based on the sound quality metrics were used to predict crackle perception
- Several had high predictive power!

# Sound quality metric results



## Top Contenders

- $\log_{10}(\text{standard deviation of instantaneous loudness}) \rightarrow 82\%$  of variance
- $\log_{10}(\text{st. dev. of instantaneous loudness normalized by short-term loudness}) \rightarrow 86\%$
- $\log_{10}(\text{st. dev. of instantaneous sharpness}) \rightarrow 92\%$

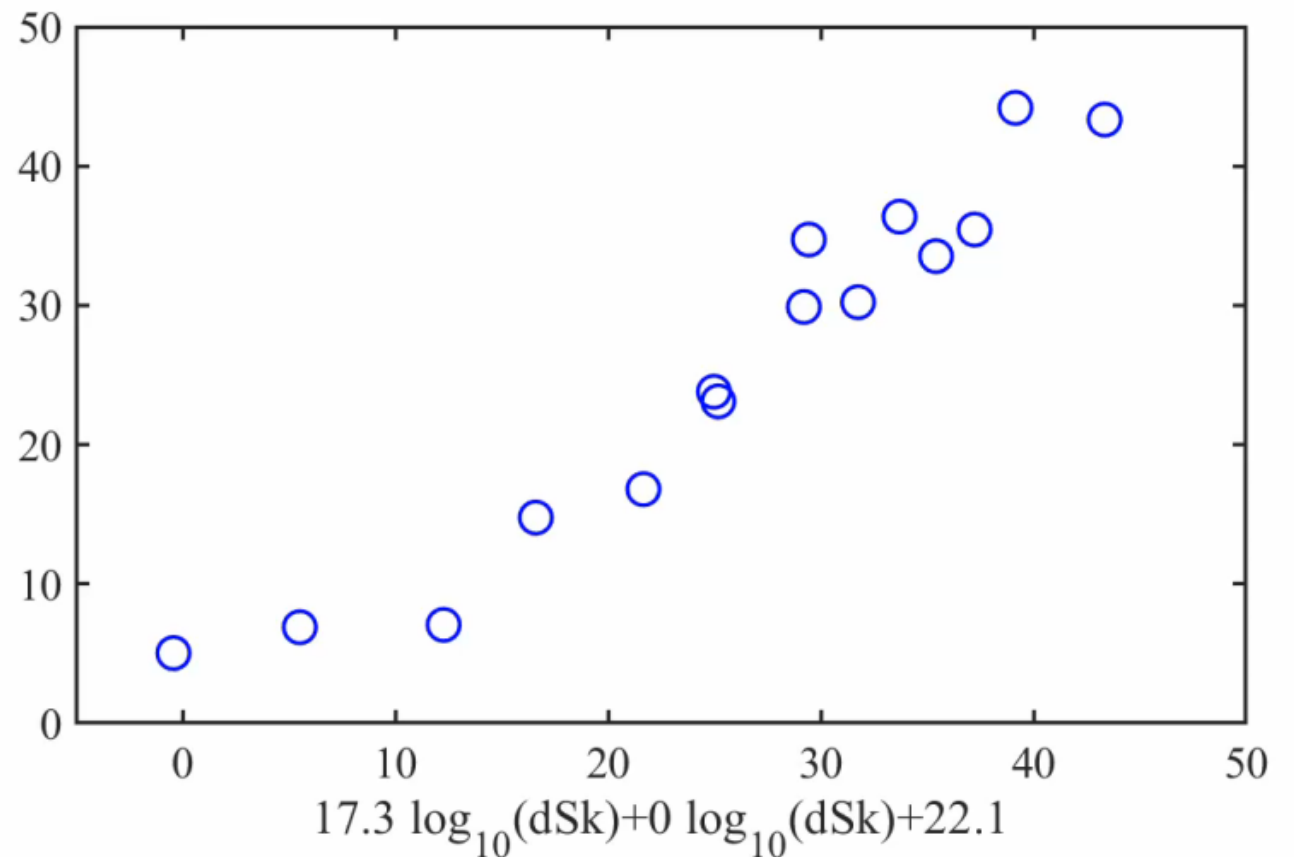




# Combined derivative skewness and st. dev. sharpness



Adding  $\log_{10}(\sigma_{sharpness})$  to  $\log_{10}\left(Sk\left\{\frac{dp}{dt}\right\}\right)$  in the linear regression increases  $r^2$  from 93% to 97%

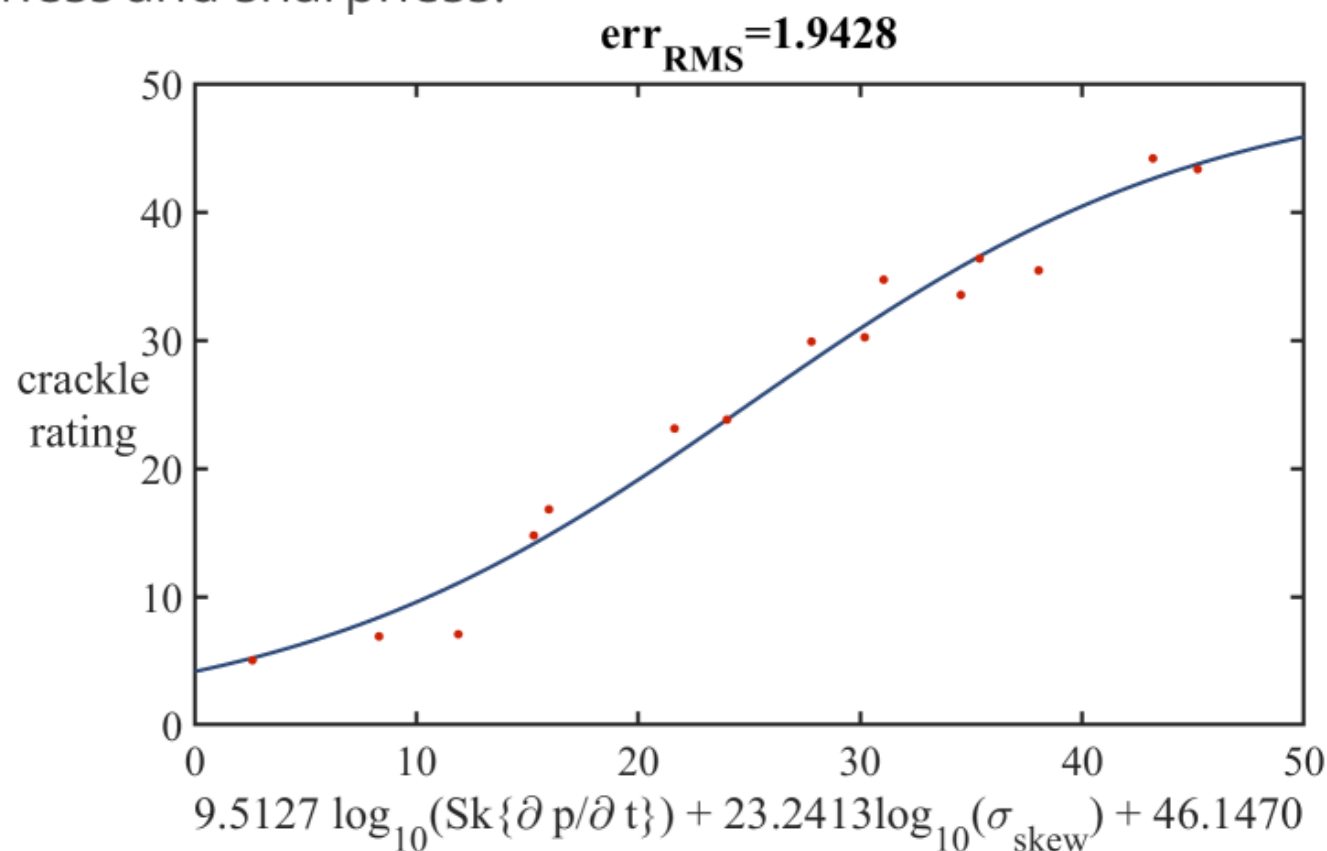


# Logistic curve fit with $Sk(dp/dt)$ and $Sk(\sigma_{sharpness})$



Repeating the logistic curve fit for the linear combination identified in the previous step

- RMS error reduced by 40% from 3.2551 to 1.948 (<1/5 of a crackle class) when using logistic curve with derivative skewness and sharpness!
- Adjustment with  $Sk(\sigma_{sharpness})$  decreases expected error by 21%  
Re: original logistic fit
- Mean error is actually lower:  
1.5530 crackle rating units
- Max error: 3.9916



# Future work



- Did not include roughness
- Did not include rough sharpness measure
- (Both of the above were strongly correlated with crackle in a prior preliminary study)
- Present measures should be validated with a larger data set to ensure more general predictive power

# Applause! Questions?

