

Reanalysis of subjective crackle ratings using a logistic curve fit



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4aNS: Jet and Launch Vehicle Noise I (Hybrid Session)



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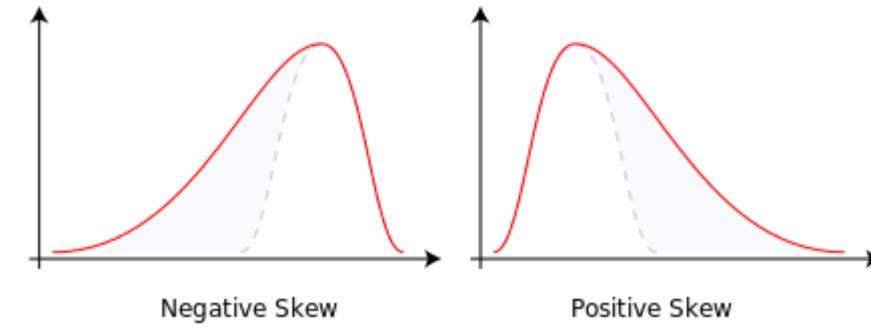
Crackle background



Without

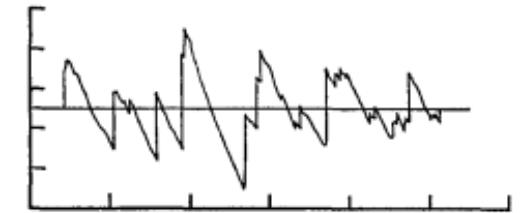


With

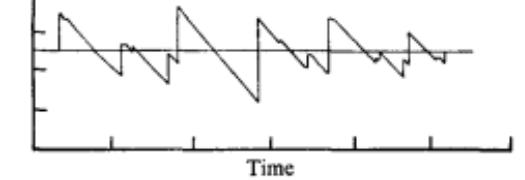


Sound quality associated with high-performance jets

- 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



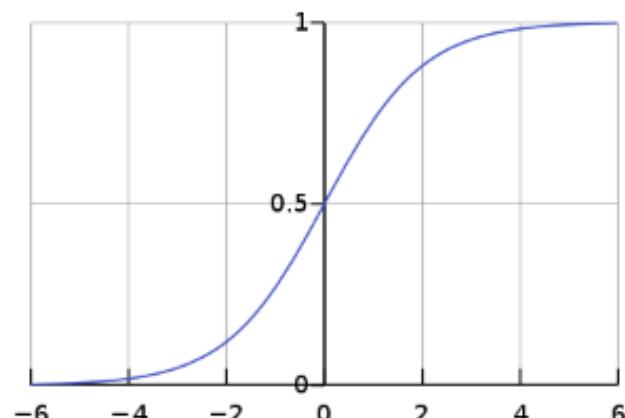
Ffowcs Williams, et al



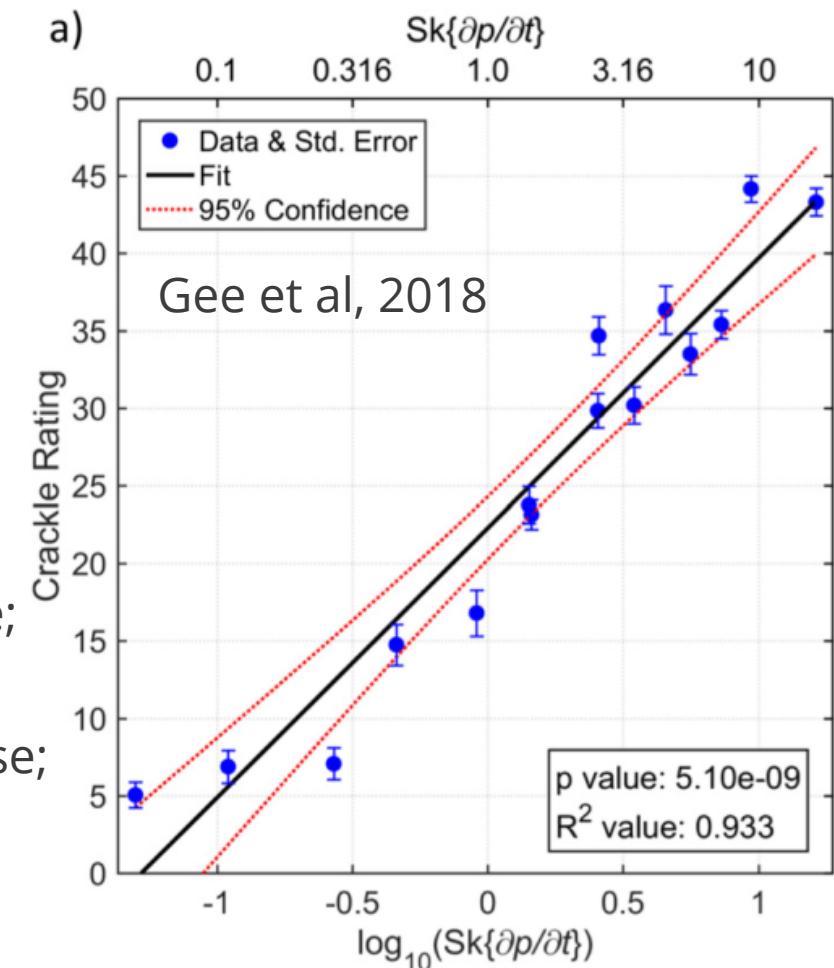
Gee et al study



- 15 waveforms varying in $Sk\{p\}$, $Sk\{\partial p/\partial t\}$; $Sk\{p\}$, 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 ($Lo\{\cdot\}$)

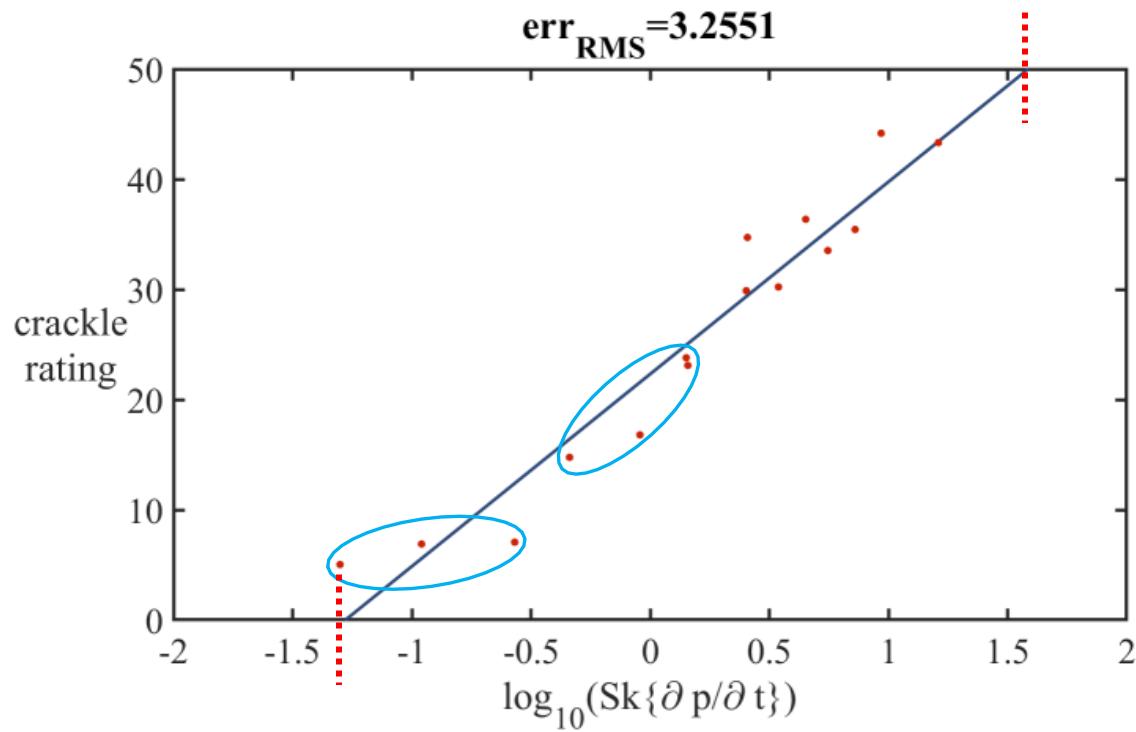
- As $Sk\left\{\frac{\partial p}{\partial t}\right\} \rightarrow 0$, $Lo\left\{\log\left\{Sk\left\{\frac{\partial p}{\partial t}\right\}\right\}\right\} \rightarrow L_{lower} = 0$
- As $Sk\left\{\frac{\partial p}{\partial t}\right\} \rightarrow \infty^+$, $Li\left\{\log\left\{Sk\left\{\frac{\partial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



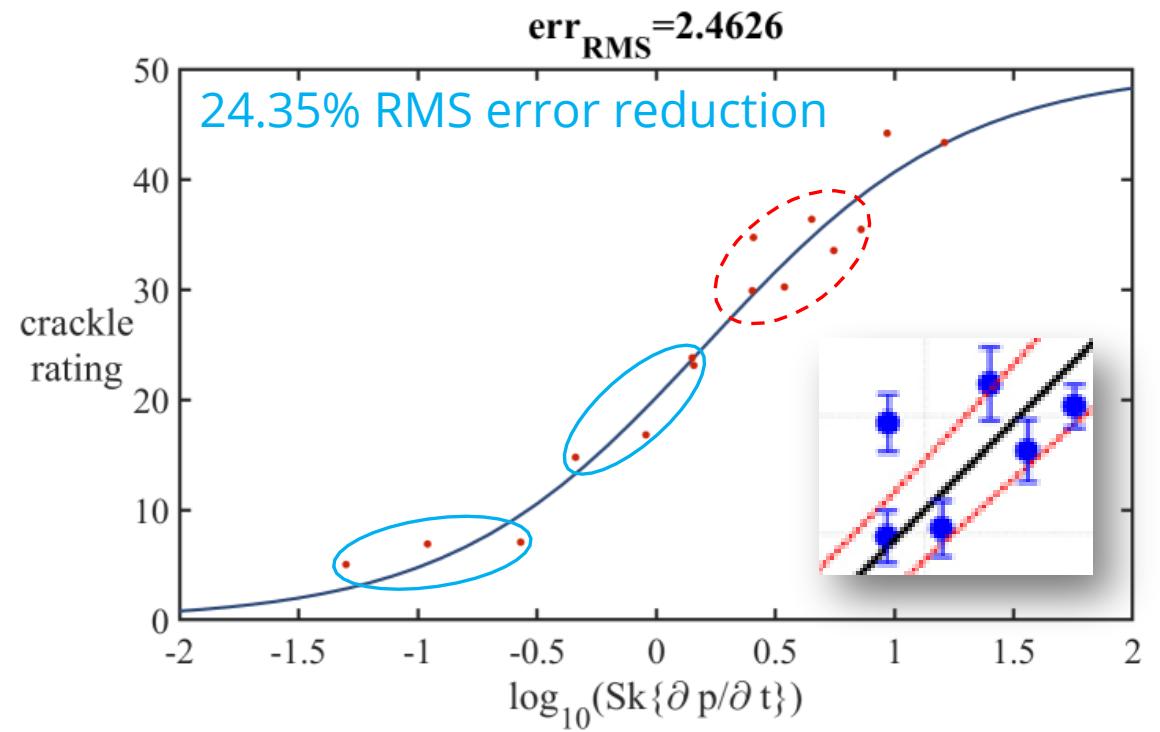
Linear vs. logistic curve fits



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



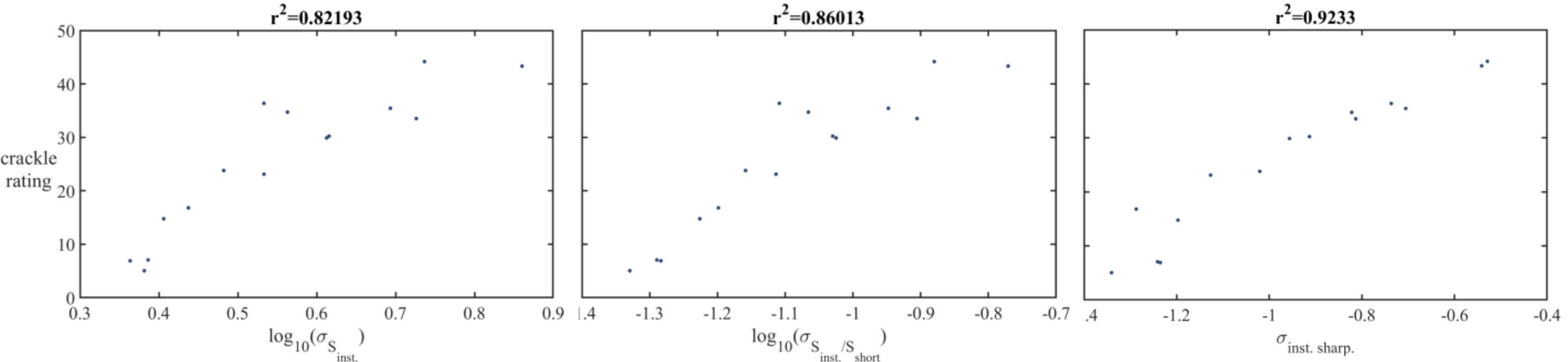
- Prior association shown between crackling sound quality and distributions of sharpness and loudness
- Sound files from subject test were retained enabling a reanalysis using metrics
- Sound calibrated to have a median loudness within 1/100 of a sone of 40 sone
- Transients were cut off
- Sound quality 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

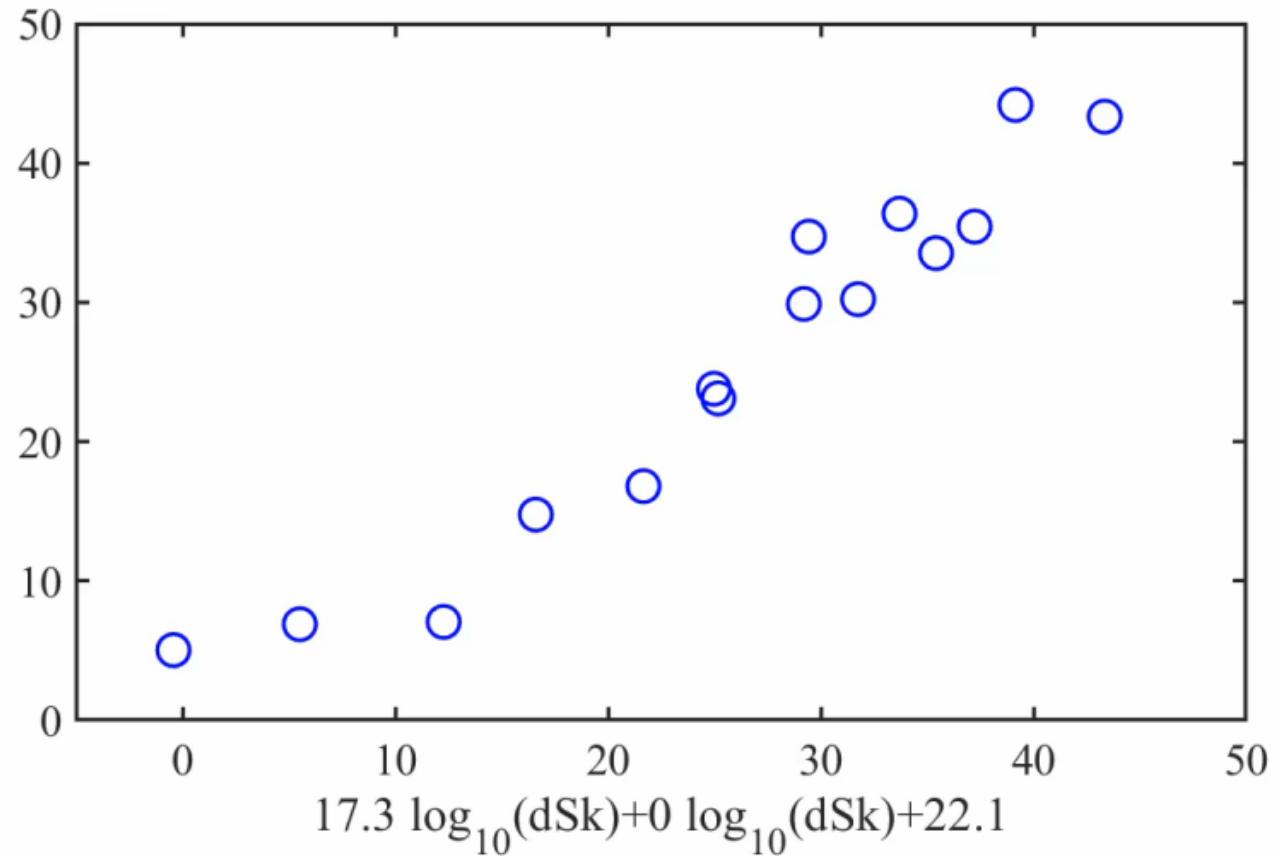
- $\log_{10}(\text{standard deviation of instantaneous loudness}) \rightarrow 82\%$ of variance
- $\log_{10}(\text{st. dev. of instantaneous loudness normalized by short-term loudness}) \rightarrow 86\%$
- $\log_{10}(\text{st. dev. of instantaneous sharpness}) \rightarrow 92\%$!



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%

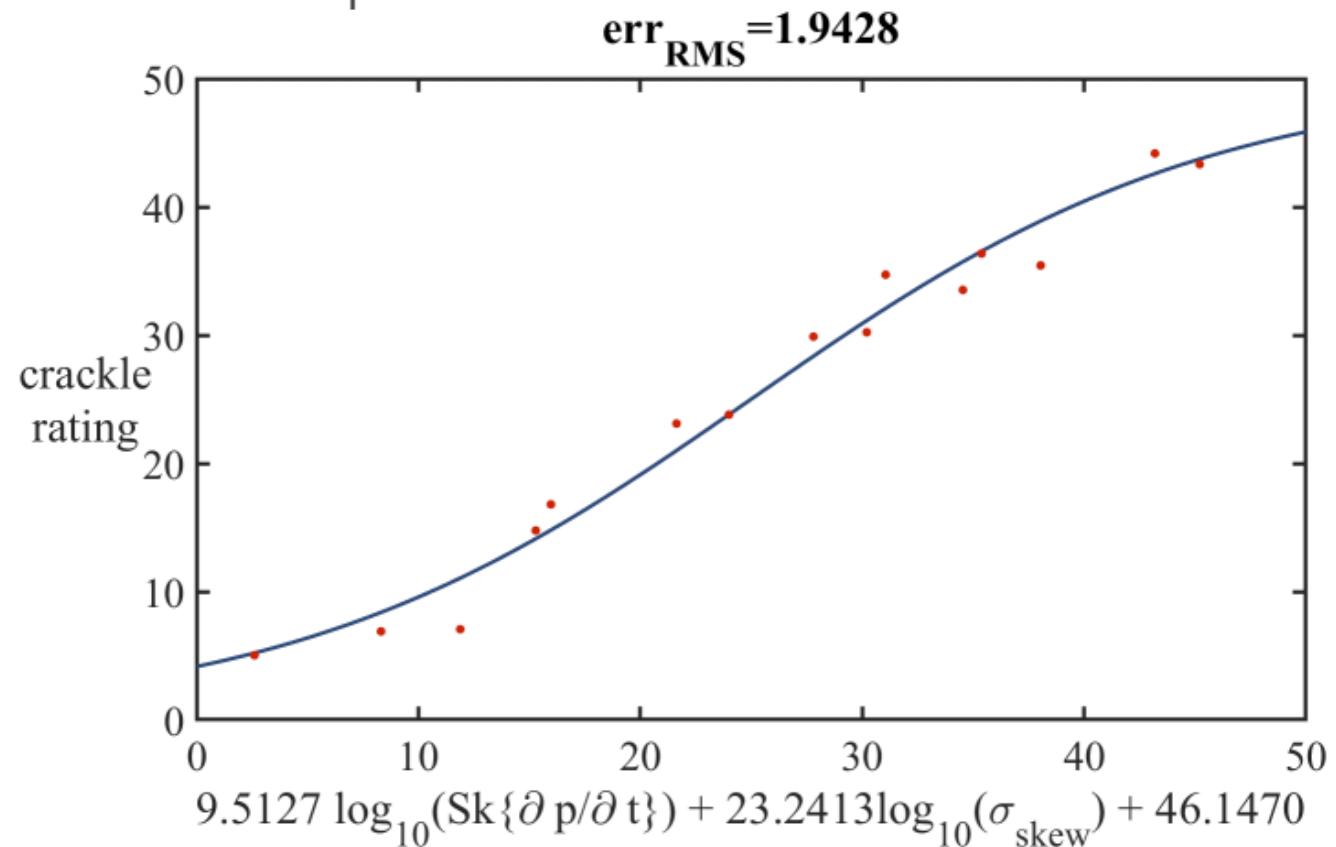


Logistic curve fit with $\text{Sk}(\partial p/\partial t)$ and $\text{Sk}(\sigma_{\text{sharpness}})$



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 $\text{Sk}(\sigma_{\text{sharpness}})$ 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?

