Air Blast Modeling

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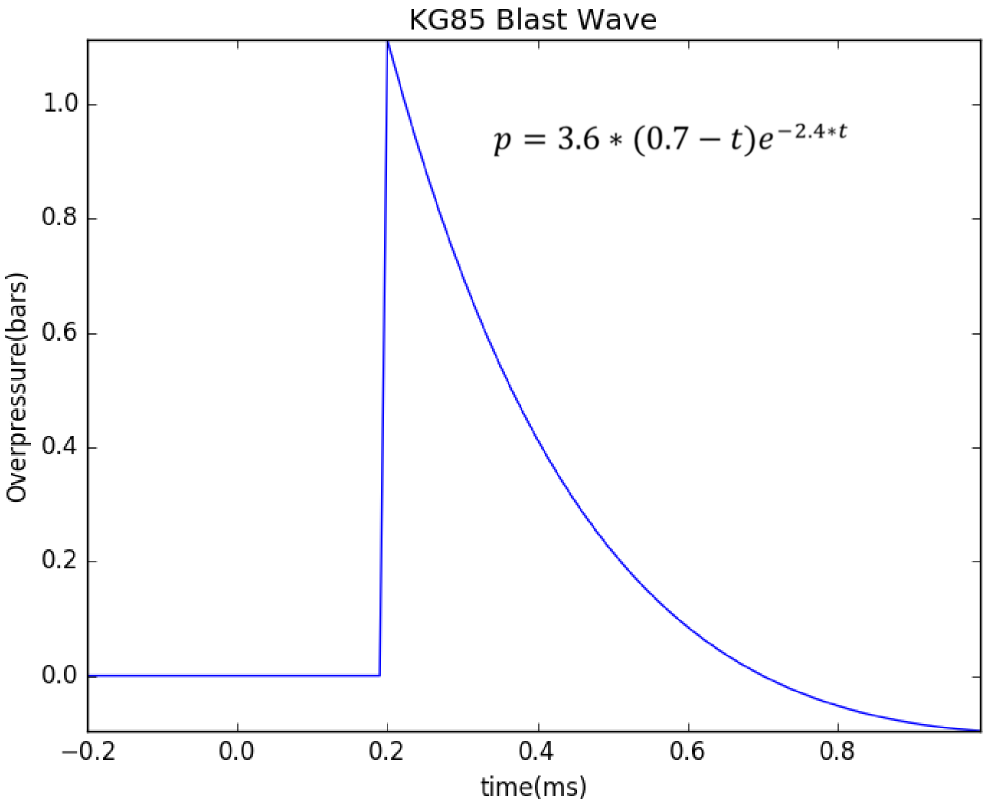
AIR-BLASTS

- Energy from an explosion near the Earth's surface causes a sudden pressure change

- Waves are generated that couple with the atmosphere

- These waves propagate as air-blast, acoustic, and infrasound waves



G. F. Kinney, K. J. Graham, Explosive Shocks in Air, 1985

Motivation

Accurate yield estimation is a vital component of the post-detonation analysis of explosive events supporting:

- nuclear forensics
- non-proliferation
- low-yield nuclear monitoring

The analysis of air blast parameters provides an estimate of yield for above ground explosions

Approach

- Make measurements on air-blasts data set in order to compare with models
- Investigate the effectiveness of LLNL yield determination algorithms using air-blast data from a series of near-surface low-yield chemical high explosive tests at Los Alamos
- Develop new more versatile models

THE EXPERIMENT

70 HE (comp B) detonations:

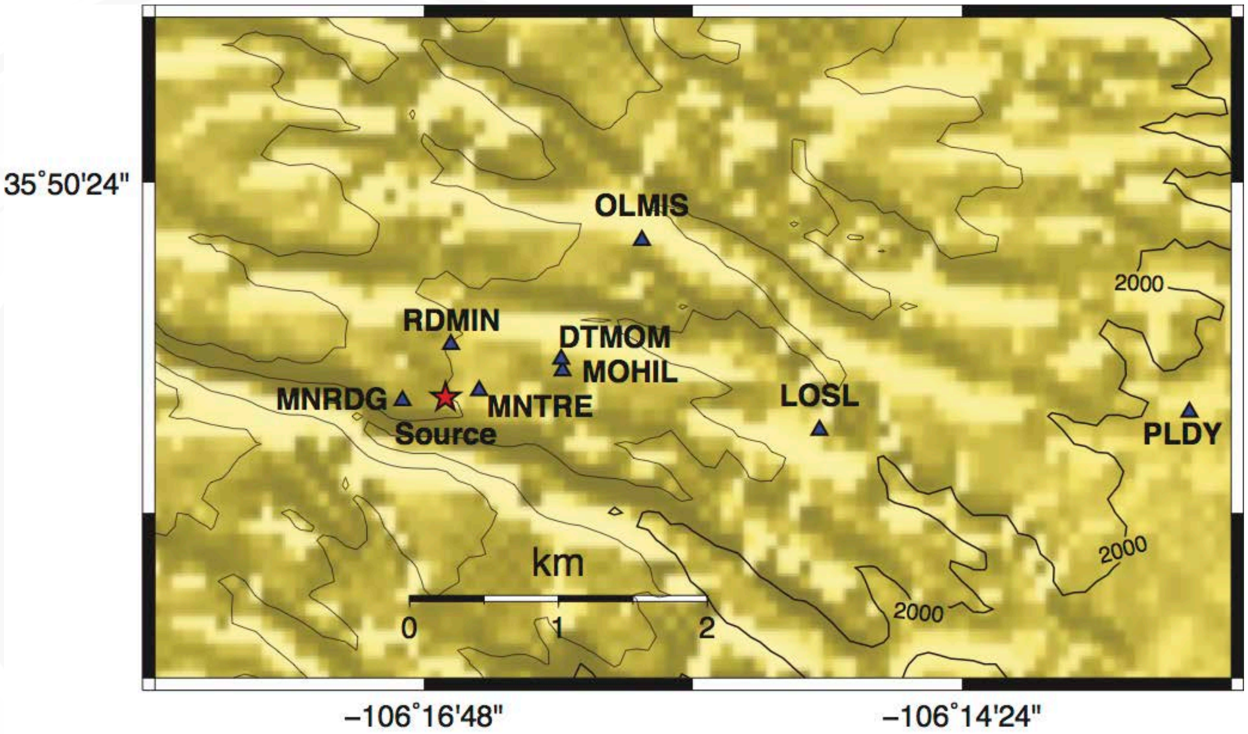
(Los Alamos National Laboratory)

- Mass: 1-15kg
- HOB: -1m-4m
- Shape: cylindrical and spherical

Included repeated explosions allowing investigation of the variability caused by:

- explosion size
- emplacement
- atmosphere
- shape

STATIONS

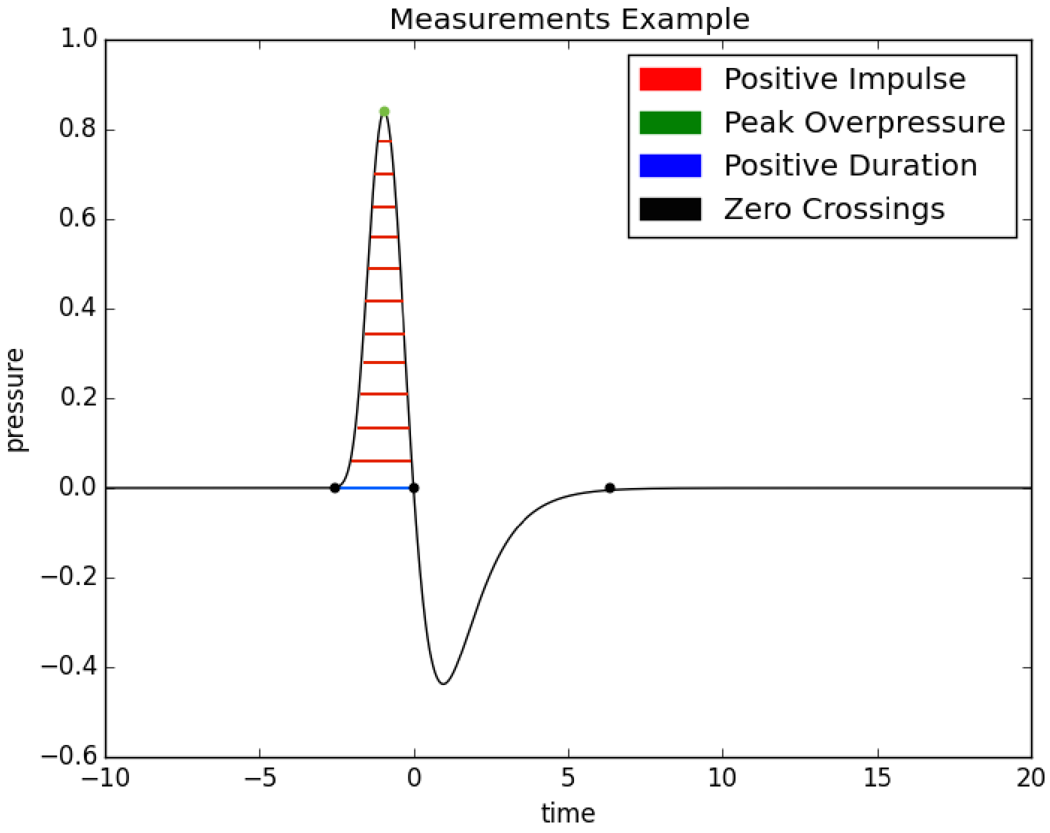


Map of the experimental configuration:
explosion location = star
overpressure stations = triangles

AIR-BLAST MEASUREMENTS: METHODS

Method:

- Determined 15 s window using estimated arrival time
- Peak pressure in window was used to define the air-blast arrival
- Defined air blast by zero crossings
- Eliminated ambiguous peaks



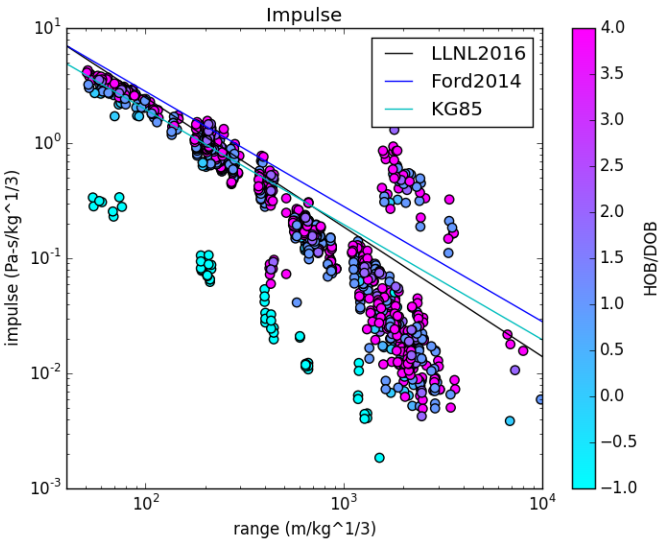
AIR-BLAST MEASUREMENTS: RESULTS

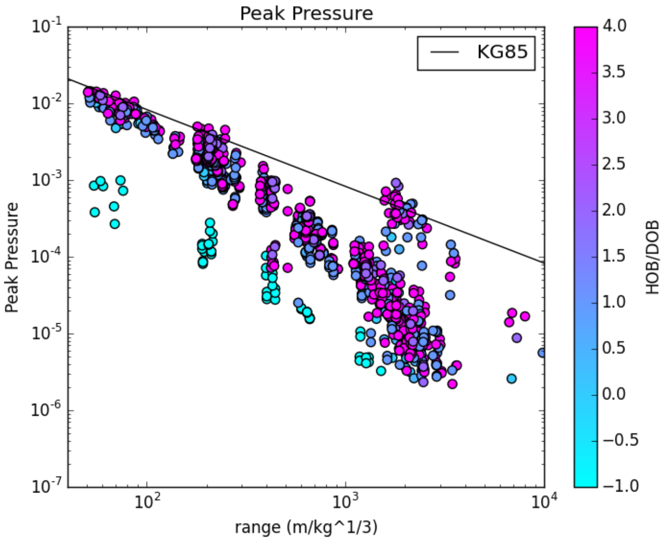
IMPULSE AND PEAK OVERPRESSURE

- Measured peak overpressure/impulse consistent with KG85 and other models up to ~ 200-500 m range
- Measurements diverge at long range
- Impulse measurements are less scattered

Note:

- Yield was derived from the TNT equivalent
- Adjusted for ambient atmospheric temperature and pressure
- Surface emplacement in a half-space was accounted for (doubled the yield)





AIR-BLAST MEASUREMENTS: RESULTS

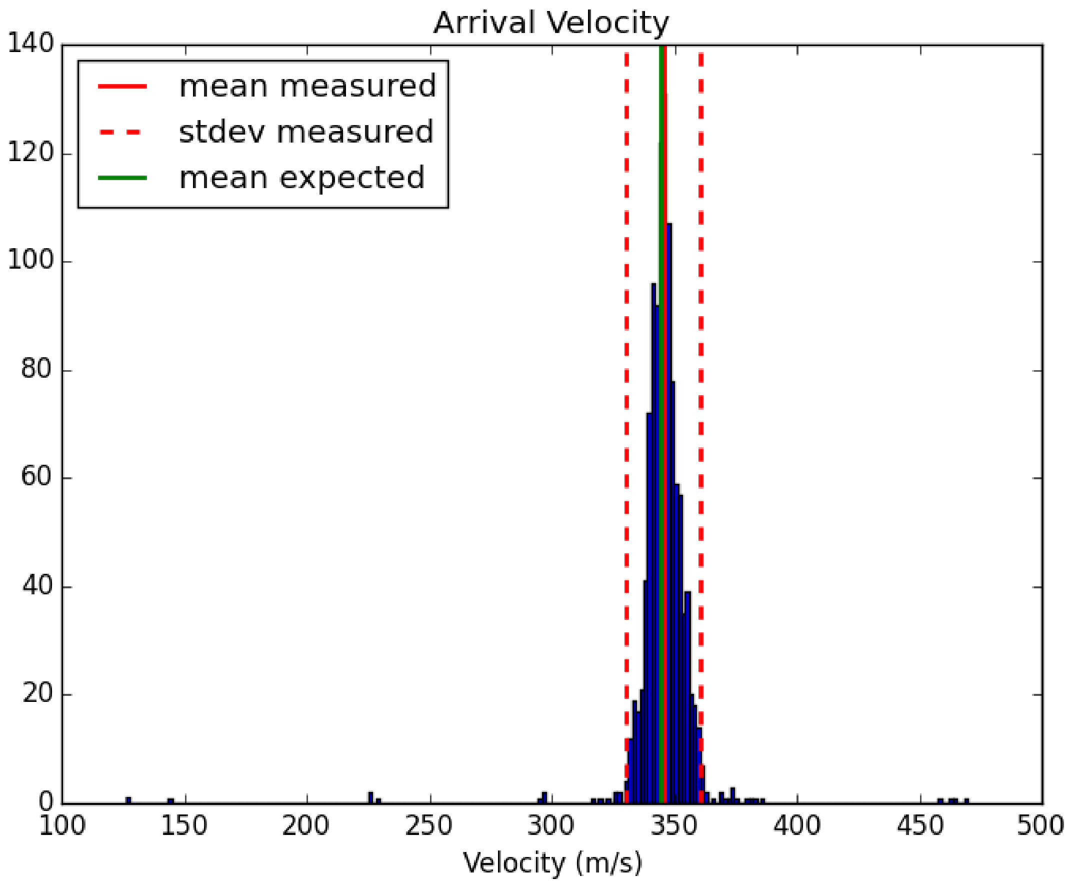
TRAVEL VELOCITY

- Tight distribution and consistent with the expected speed of sound in air

- Confirms our method of measuring the blast arrival is sufficiently accurate

- Extreme outliers due to incorrect meta-data

- No trend of the arrival velocities with HOB or yield

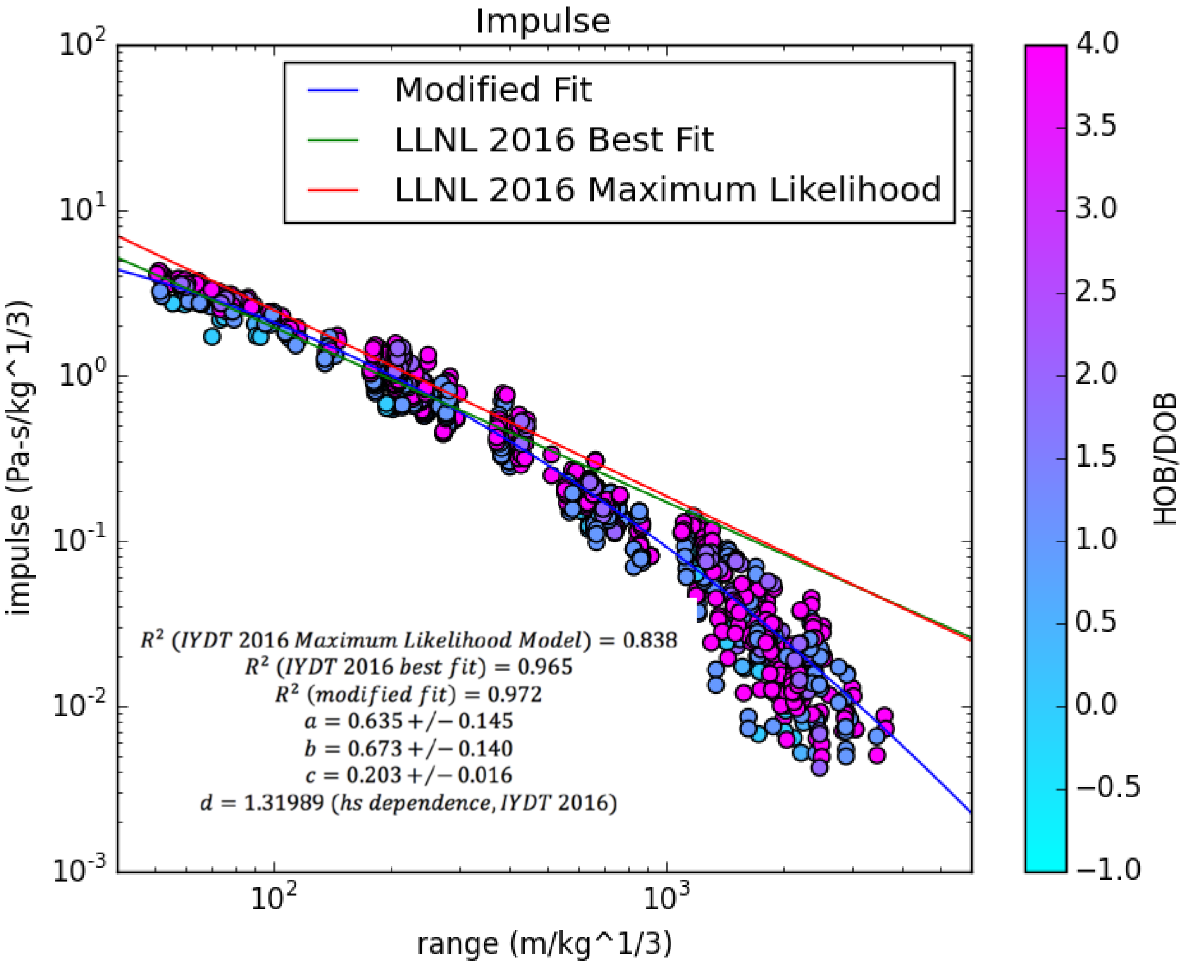


AIR-BLAST MEASUREMENTS: NON-LINEAR MODELS

Future Work:

- Develop a parameterized impulse vs. range model that takes into account propagation effects

- Use nonlinear models to extend the range over which LLNL yield estimation is effective



Modified model includes curvature to fit the impulse better at longer range

YIELD ESTIMATION: METHODS

LLNL software uses positive impulse to determine yield from air-blasts using 2 methods:

Grid search method

- Samples the search space uniformly (log10(Yield) space/linear HOB space
- Fixed step size and range for the grid search
- Likelihood = the sum of differences between the data and predictions

MCMC method

- Markov Chain Monte Carlo stochastic inversion
- Guided random walk
- Initial step size is user determined then automatically updated by the algorithm
- User specifies the number of MCMC chains

YIELD ESTIMATION: RESULTS

Compared the LLNL software estimated yields to the true yields for 67 detonations:

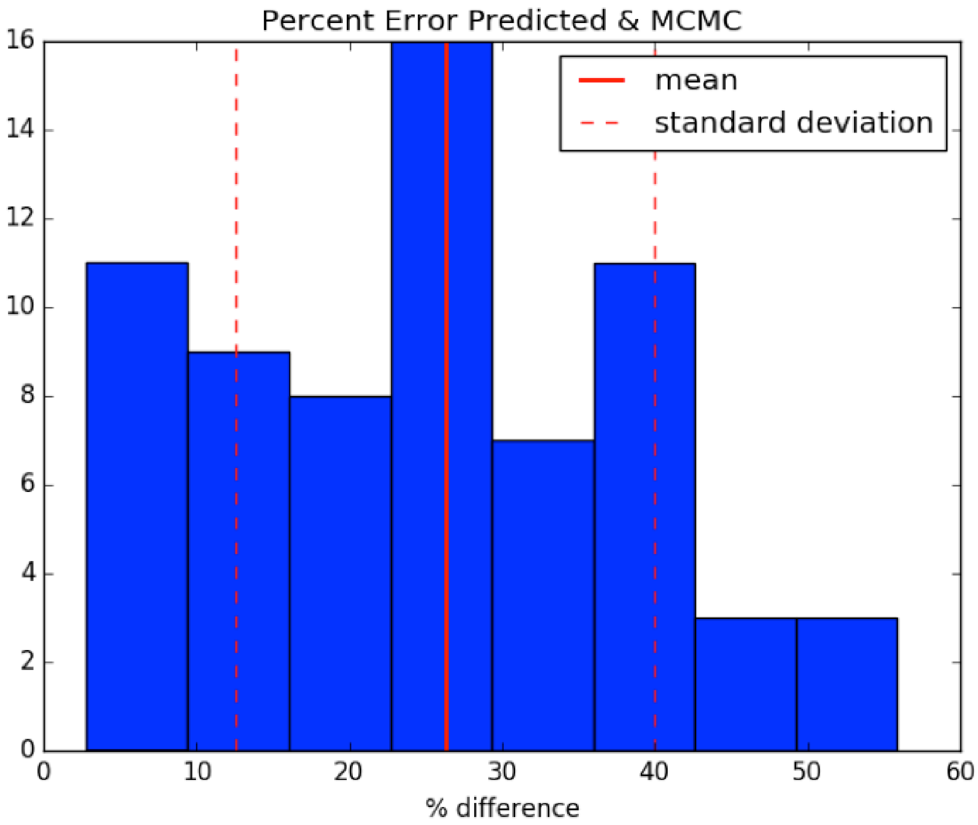
Past Results

25% absolute yield error 50% of events

50% absolute yield error 78% of events

New Results

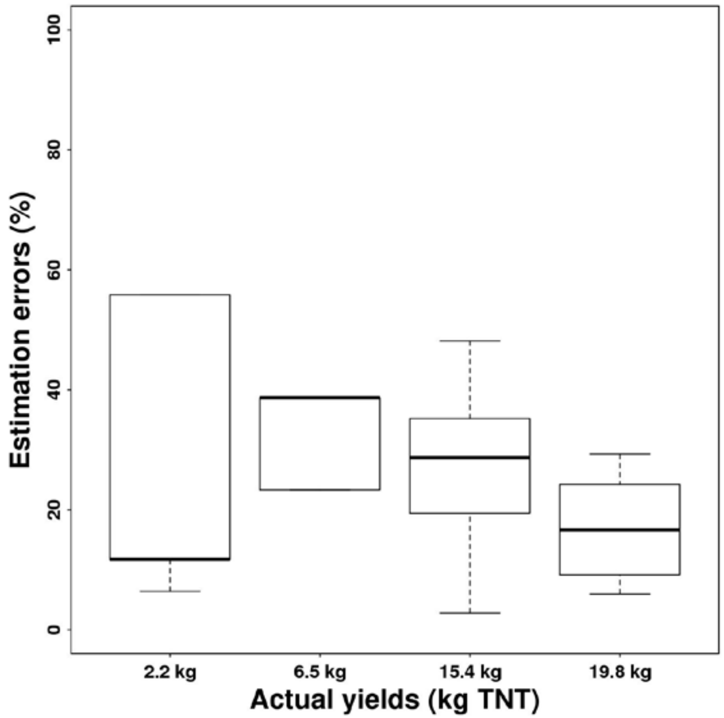
Mean absolute yield error < 30%

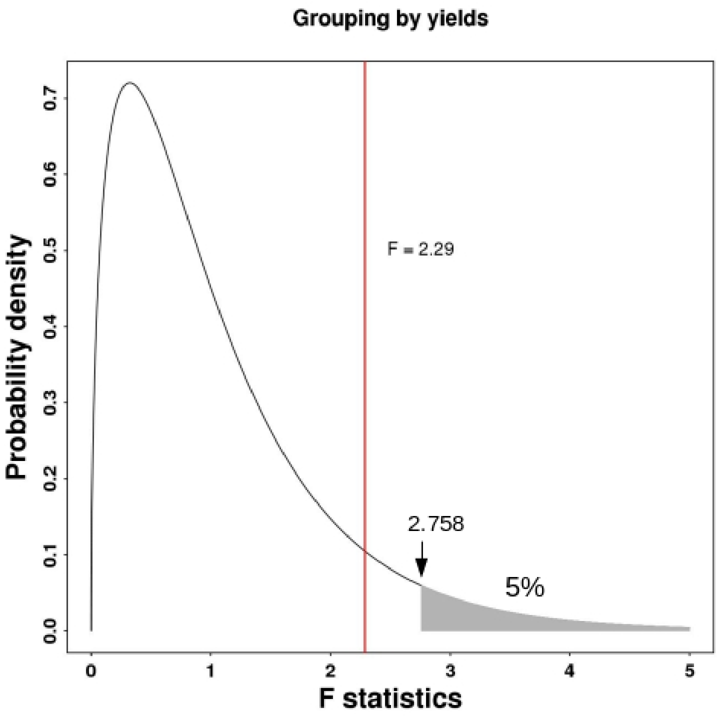


Conclusion:
The LLNL software is applicable to very small yield explosions.

YIELD ESTIMATION: ANOVA TEST

ANOVA: Looks for statistically significant differences between groups by comparing the means



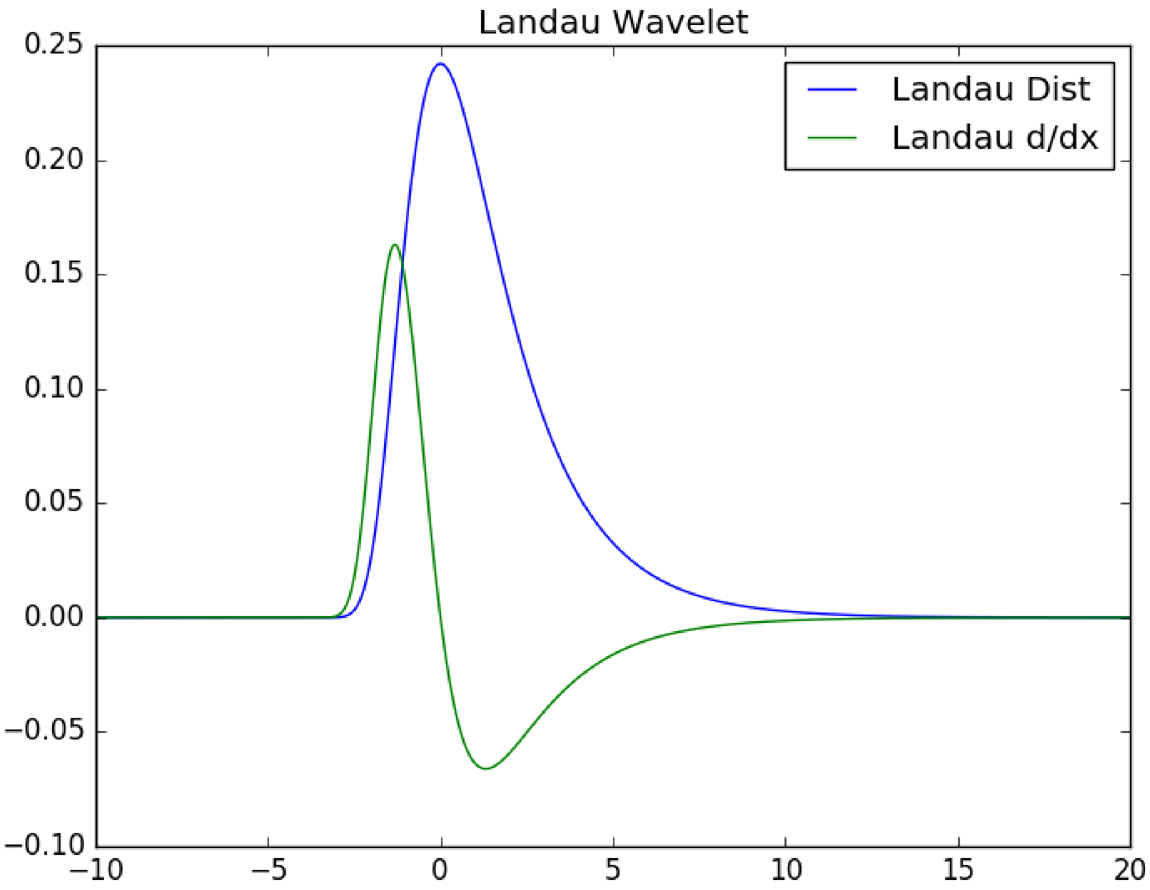


Source of variance	Sum of square	Degree of freedom	Mean square	F statistics
Between Groups	1290.581	3	430.1937	2.287
Within Groups	11285.08	60	188.0847	
Total	12575.58	63	199.6124	

- The F value (ratio of variances) falls into 95% probability region (below F=2.758)
- Means of the **% difference of the yield groups are not significantly different** at 5% significance

AIR BLAST MODELING: THE LANDAU WAVELET

- Based on derivative of the approximate Landau distribution (Moyal, 1955)
- Continuous, differentiable
- Resembles real air blast data
- Impulse balanced negative phase



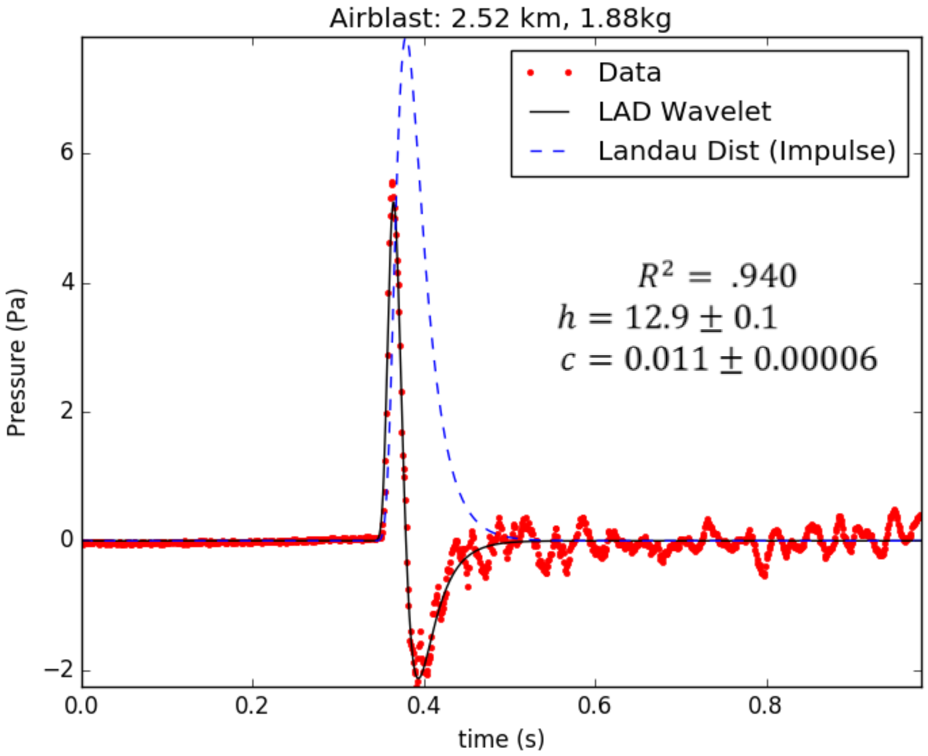
$$Landau\ PDF\ Approximation = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}(x+e^{-x})}$$

(Moyal, 1955)

$$\frac{d}{dx}(Landau\ PDF) = \frac{1}{2\sqrt{2\pi}} e^{-\frac{1}{2}(3x+e^{-x})}(1-e^{x})$$

AIR BLAST MODELING: PRELIMINARY FITTING

- Used least-squared method to fit functional form to small yield air blast data
- Does not yet include shape parameter (s)
- Set horizontal position based on measured zero crossing
- Vertical and horizontal scaling were fit parameters
- Will experiment with fitting a generalized version of the Landau wavelet to large air-blast data set



$$Pressure = \frac{h}{2} * e^{-\frac{1}{2}\left(\frac{3(x-p)}{c} + e^{-\frac{x-p}{c}}\right)}\left(1 - e^{\frac{(x-p)}{c}}\right)$$

h, c, p control position and scaling
p is fixed to the zero crossing

AIR BLAST MODELING: COMPARING MODELS

Friedlander (1946): $(1-\tau)e^{-\alpha\tau}$

Brode (1955): $\tau(1-\tau)e^{-2\alpha\tau}$

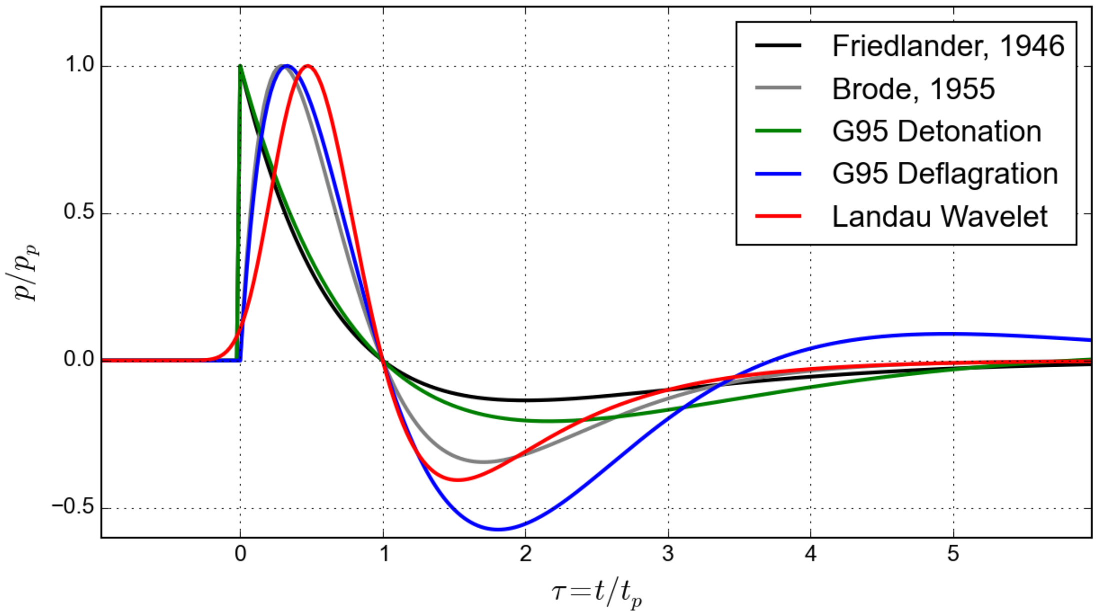
G95 Detonation: $(1-\tau)(\tau_0-\tau)e^{-\alpha\left[\frac{\tau_0+1}{2\tau_0}\right]\tau}$

G95 Deflagration: $\tau(1-\tau)(\tau_0-\tau)e^{-\alpha\left[\frac{\tau_0+1}{\tau_0}\right]\tau}$

Landau Wavelet: $\left(e^{\frac{5}{2}(1-\tau)}-1\right)e^{\frac{5}{4}\alpha(1-\tau)}e^{-\frac{1}{2}e^{\left[\frac{5}{2}(1-\tau)\right]}}$

First moment, or total impulse, vanishes for $\alpha = 1$

Generalized Landau Wavelet: $\left(e^{s(1-\tau)}-1\right)e^{\frac{1}{2}s\alpha(1-\tau)}e^{-\frac{1}{2}e^{s(1}}$



- Followed the procedure of Garces (2017) to scale the LAD wavelet according to peak overpressure and positive pulse duration
- Main advantage over other models is differentiability
- A continuous differentiable function is needed for finite difference modeling
- Generalized Landau wavelet and other models will be tested against real air blast data

CONCLUSIONS

PROGRESS

- Tested LLNL yield estimation software
- Confirmed LLNL models developed at higher yield (20-1000x larger) are applicable to small yield detonations
- Compared LLNL 2016 impulse vs. range model with measurements
- Developing a new more versatile air blast model
- Scaled LAD wavelet following the procedure of Garces (2017)

NEXT STEPS

Further investigate non-linear scaled impulse models

- Extend yield estimation to longer range

Test air blast models against large air-blast data set

- Check goodness of fit, canonical parameters, impulse fit
- Look for direct relationships between model parameters and yield
- Apply air-blast model in waveform-based yield estimates Kim and Rodgers (2016)

QUESTIONS?