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AIRBLAST EQUIVALENT WEIGHT AND YIELD DETERMINATIONS BASED ON MEASUREMENT OF ENERGY AND OTHER BLAST WAVE PARAMETERS

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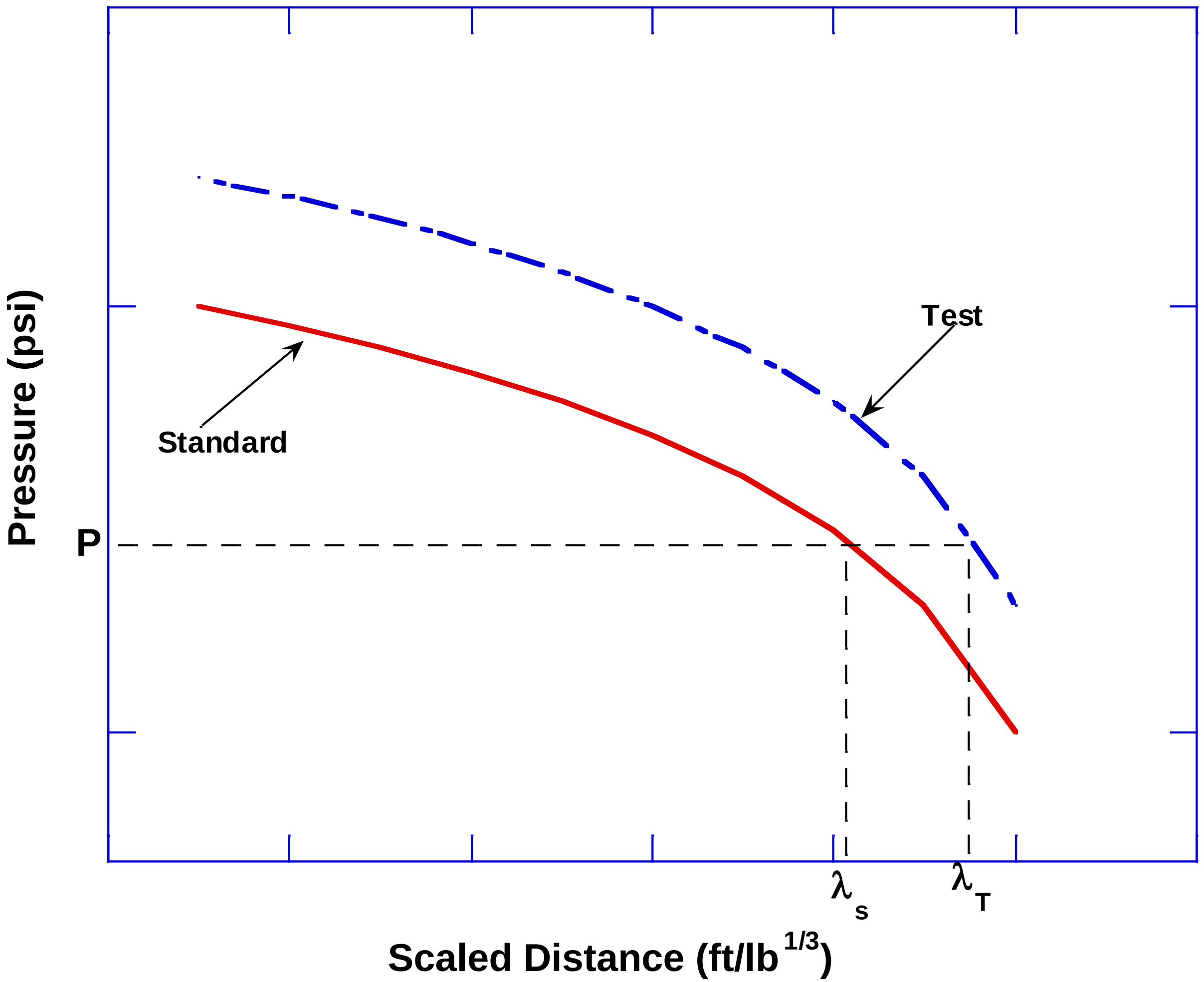
OVERVIEW

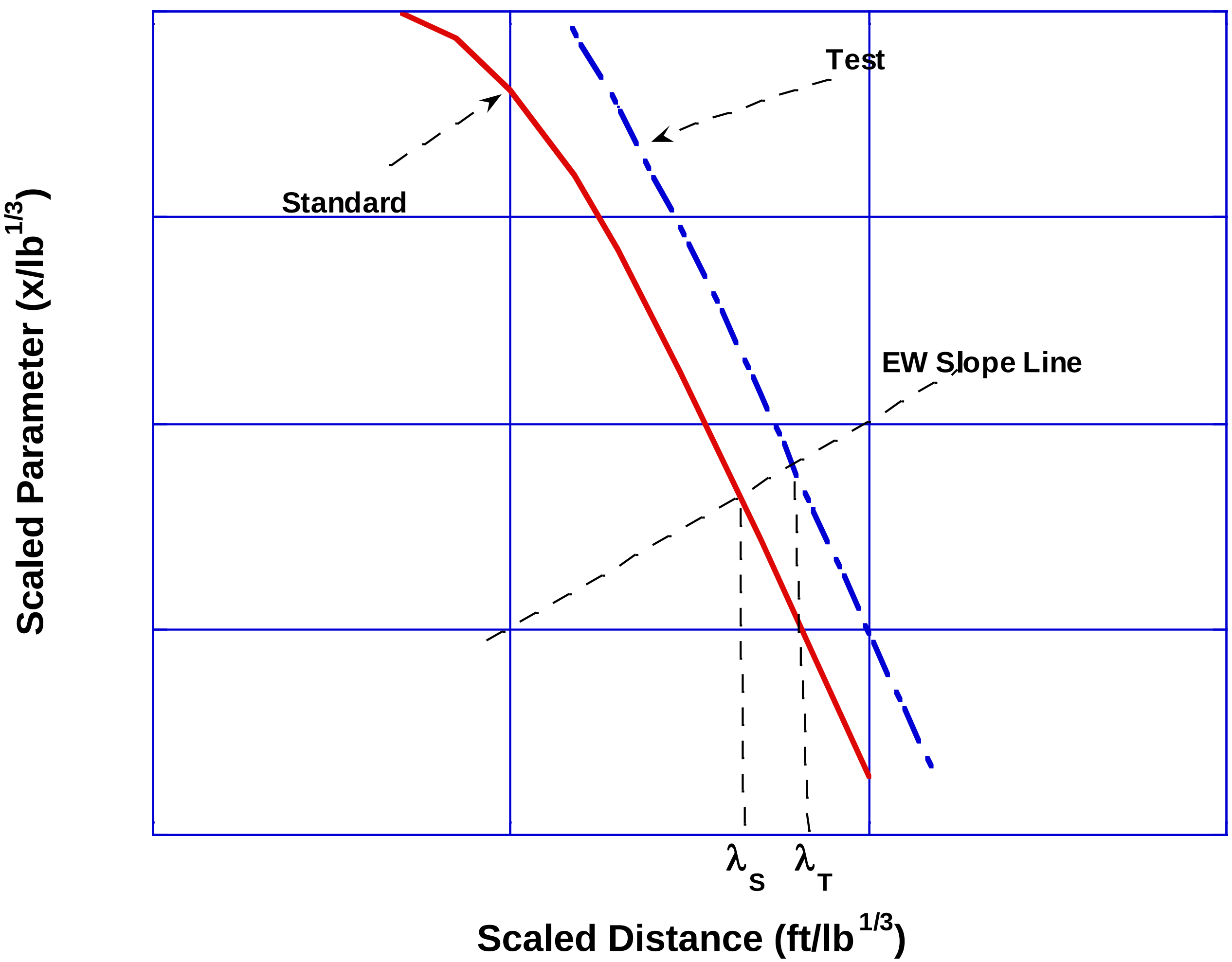
- Classic Equivalent Weight Defined
- New Methodology Description
- Sample Problem
- Shockwave Energy Definition
- Shockwave Energy Application to Pressure-Time Waveform
- Shockwave Energy Closed Form Solution for Modified Friedlander Waveform
- Summary

EQUIVALENT WEIGHT ANALYSIS FOR PRESSURE



$$EW_p = (\lambda_T/\lambda_S)^3$$

EQUIVALENT WEIGHT ANALYSIS FOR SCALED PARAMETERS, X (TIME OF ARRIVAL, DURATION, IMPULSE)



$$EW = (\lambda_T/\lambda_S)^3$$

Values of scaled range (λ) are taken from the test and standard curves at the intersections of a sloped line corresponding to the slope of the logarithmic cycles of the graph.

AN ALTERNATIVE CALCULATIONAL METHODOLOGY

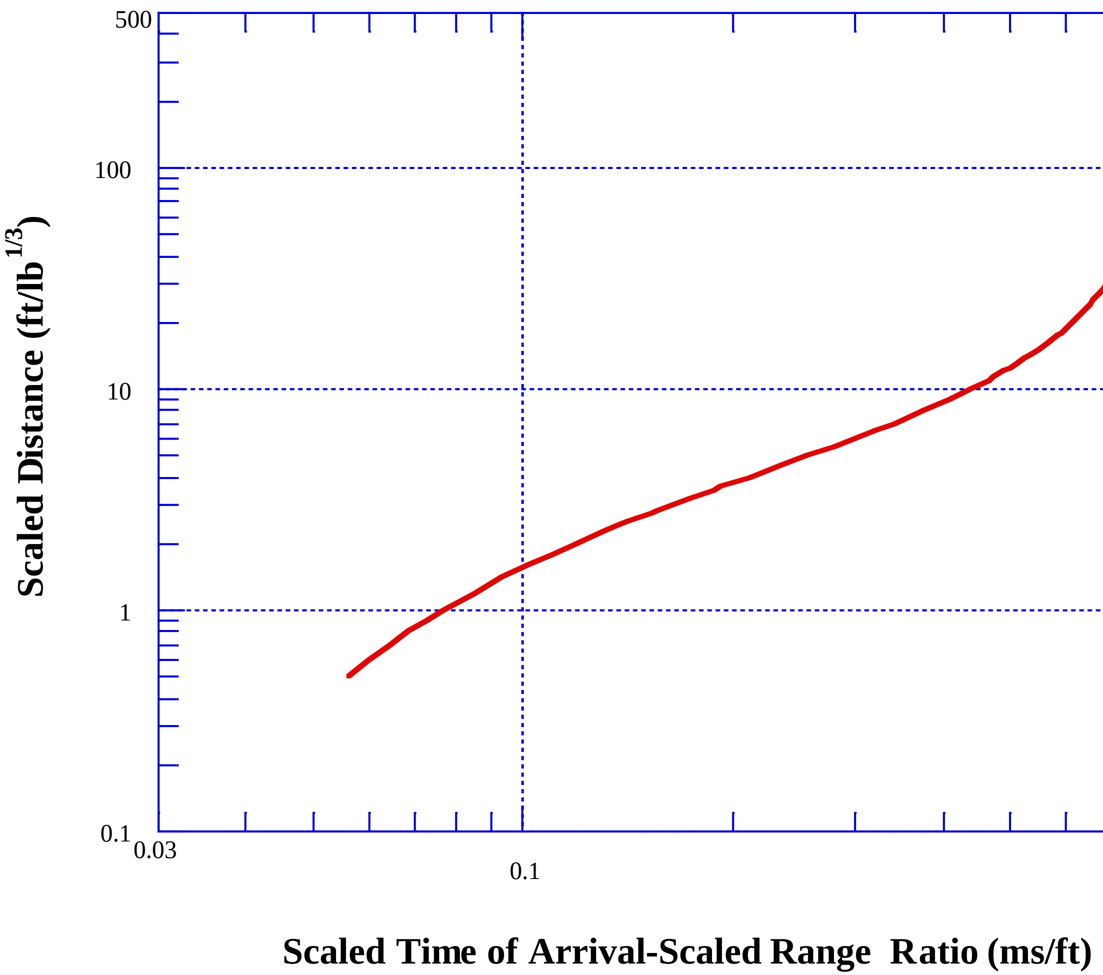
- Assume that the "Standard" Explosive is a hemispherical TNT surface burst as defined by Kingery and Bulmash (ARBRL-TR-02555)
- For each scaled parameter, X (time of arrival, duration, impulse), consider the ratio of the scaled parameter to the scaled distance

$$(X/W^{1/3})/\,(R/W^{1/3}) = X/R$$

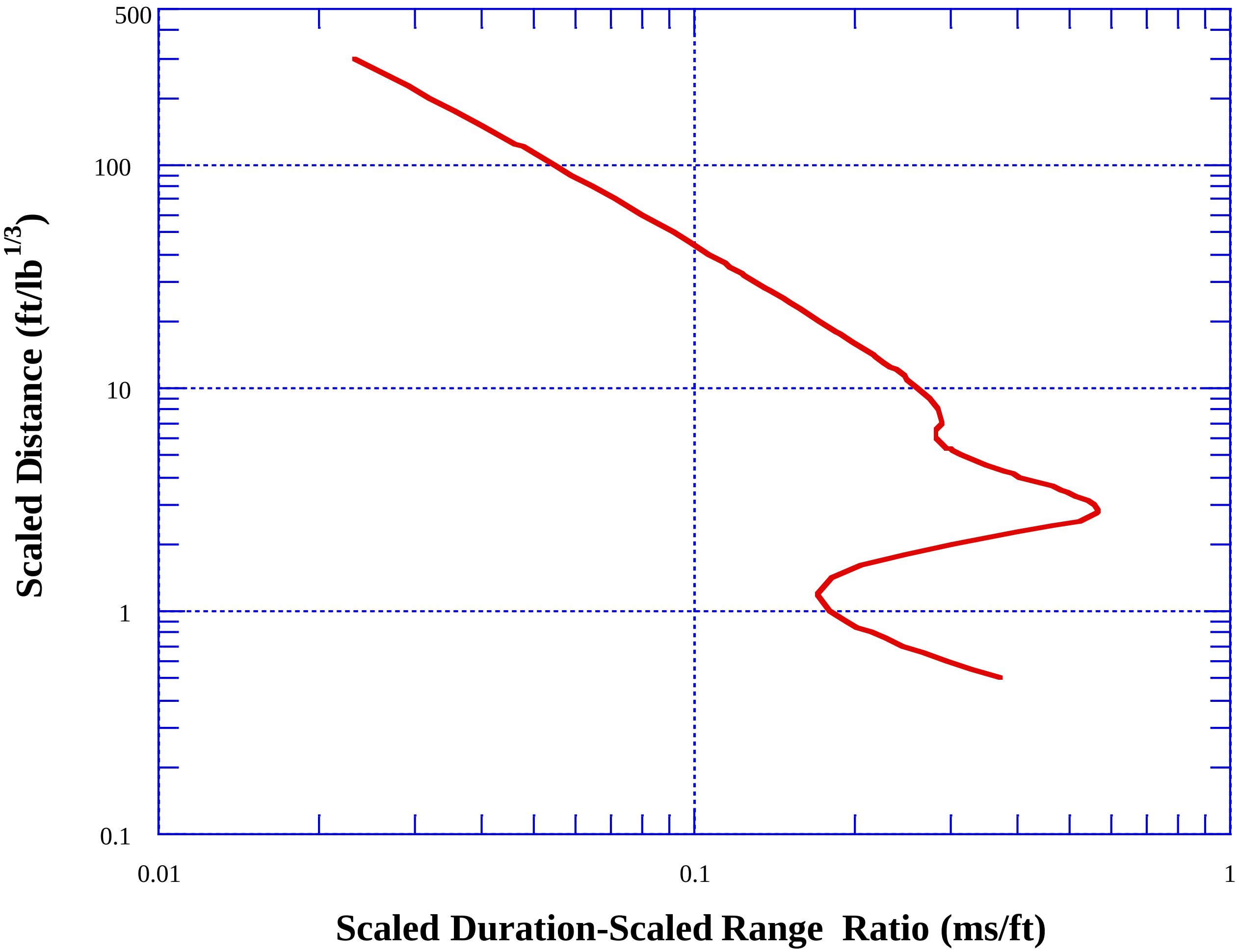
(note: relation works in both Imperial and SI units)

- Next consider the scaled distance as a function of this parameter ratio for each scaled parameter of interest
- To calculate a yield based on a given scaled parameter ($X/W^{1/3}$) at the measurement range R, perform the following steps:
  - Calculate the ratio of the parameter to the range (X/R)
  - Enter the appropriate graph and determine the hemispherical TNT scaled distance corresponding to that parameter ratio
  - Effective weight of TNT = (actual range R/effective TNT scaled distance)^3
  - Equivalent weight = Actual weight/Effective Weight

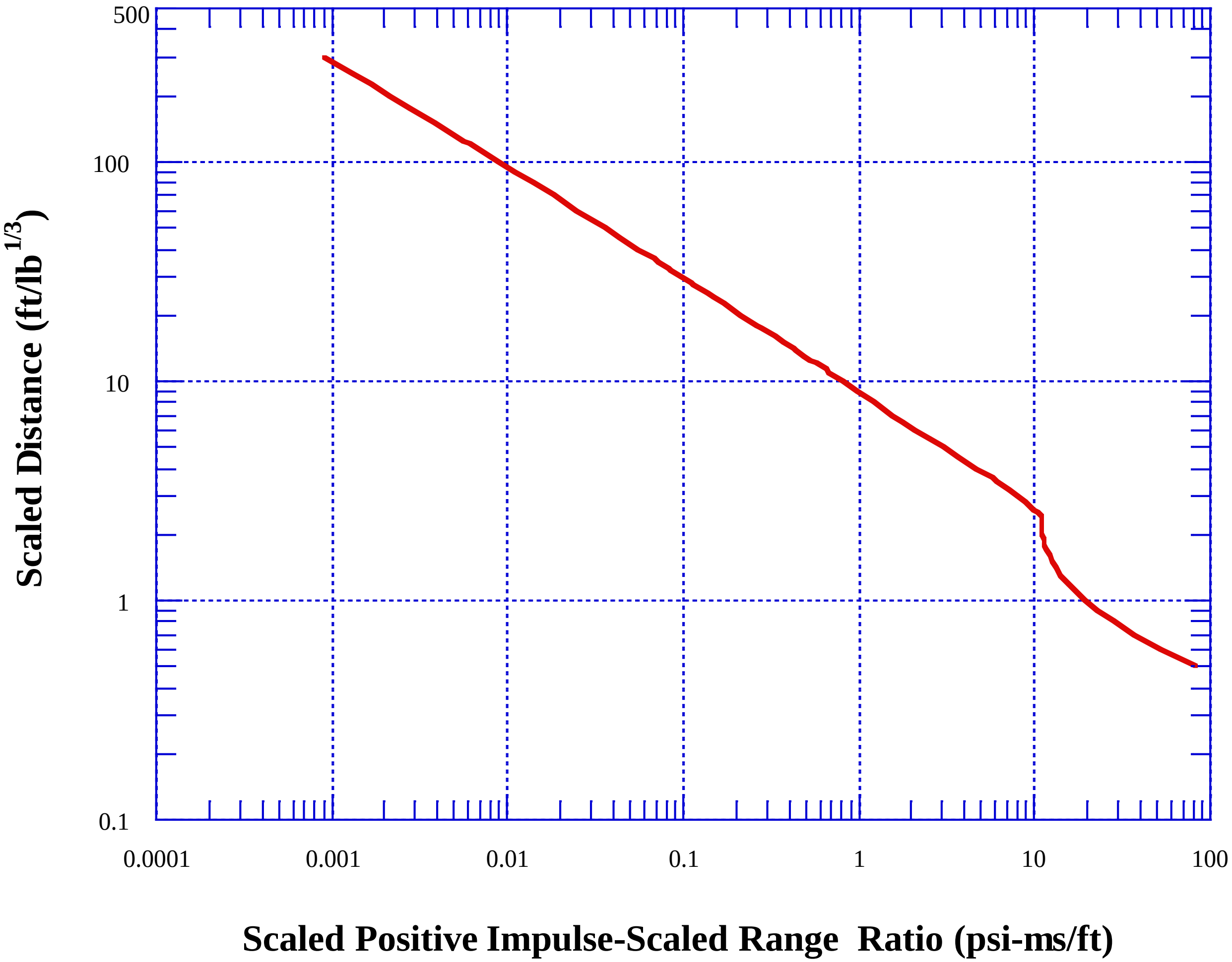
SCALED TIME OF ARRIVAL/ SCALED DISTANCE RATIO



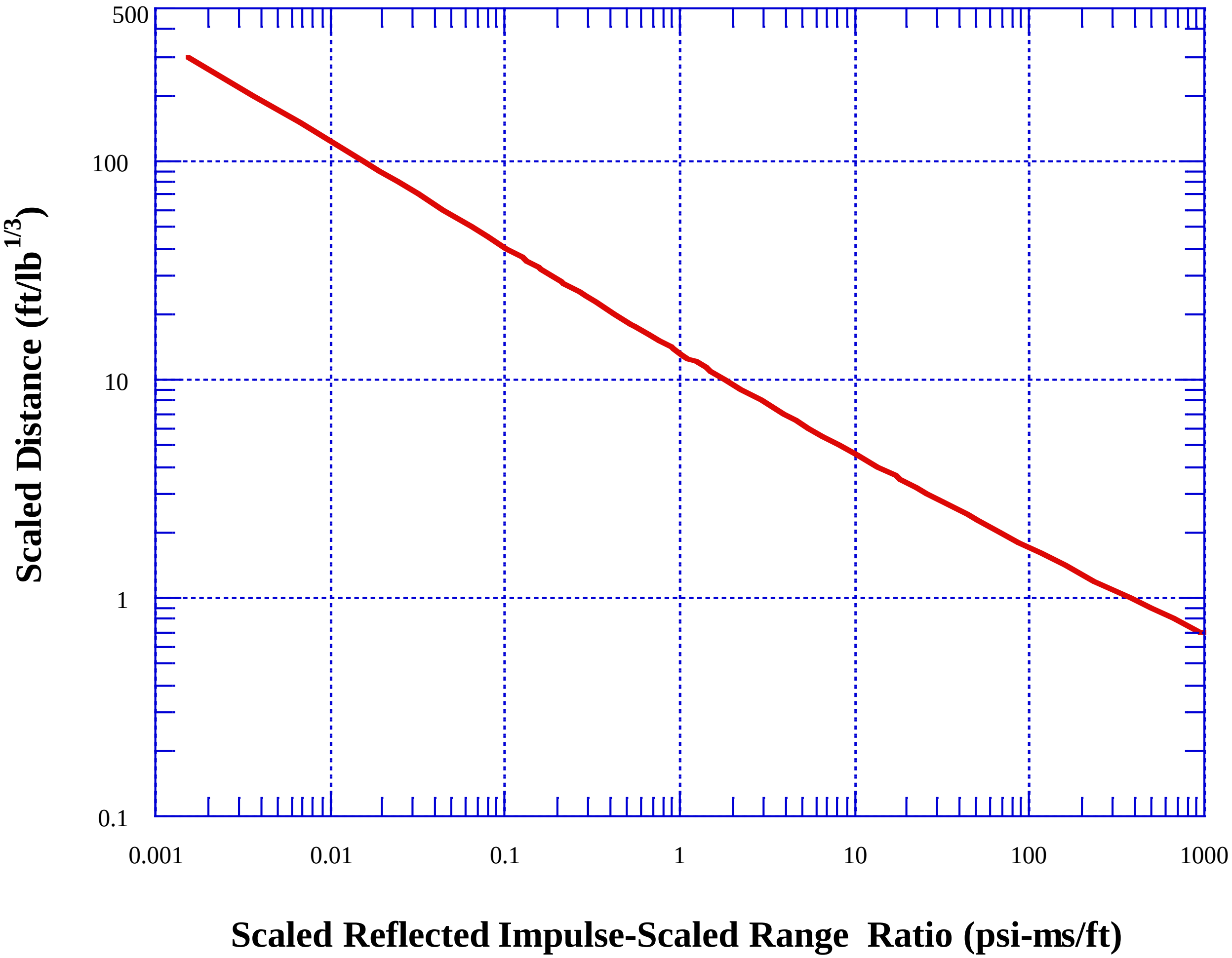
SCALED DURATION/ SCALED DISTANCE RATIO



SCALED POSITIVE IMPULSE/ SCALED DISTANCE RATIO



SCALED REFLECTED IMPULSE/ SCALED DISTANCE RATIO



SAMPLE CALCULATION

- An unknown material weighing 500 lb detonates. At a range of 90 ft, the following parameters are measured:
  - Time of arrival = 40.0 ms
  - Positive duration = 21.0 ms
  - Positive impulse = 60.0 psi-ms
- Based on these values, what is the effective TNT hemispherical weight and the effective hemispherical TNT equivalence?

SAMPLE CALCULATION (CONTINUED)

- Time of Arrival
  - TOA ratio = 40.0/90.0 = 0.44 ms/ft
    - Effective hemispherical scaled distance = 10.05 ft/lb$^{1/3}$
    - Effective TNT yield = $(90/10.05)^3$ = 718 lb
    - Effective TNT Equivalence = (718/500) = 1.44
- Duration
  - Duration ratio = 21.0/90.0 = 0.23 ms/ft
    - Effective hemispherical scaled distance = indeterminate
    - Effective TNT yield = $(90/???)^3$ = indeterminate
    - Effective TNT Equivalence = (718/500) = indeterminate
- Positive Impulse
  - Impulse ratio = 60.0/90.0 = 0.67 psi-ms/ft
    - Effective hemispherical scaled distance = 11.10 ft/lb$^{1/3}$
    - Effective TNT yield = $(90/11.10)^3$ = 533 lb
    - Effective TNT Equivalence = (533/500) = 1.07

HEMISPHERICAL EQUIVALENCE CALCULATOR

Hemispherical Equivalence Calculator (HEC)

Version 2.0

Developed by Lippe D. Sadwin and Michael M. Swisdak, Jr.

23 May 2018

- Tool developed to automate calculation process
- Tool available from author
- mswisdak@apt-research.com

SHOCKWAVE ENERGY

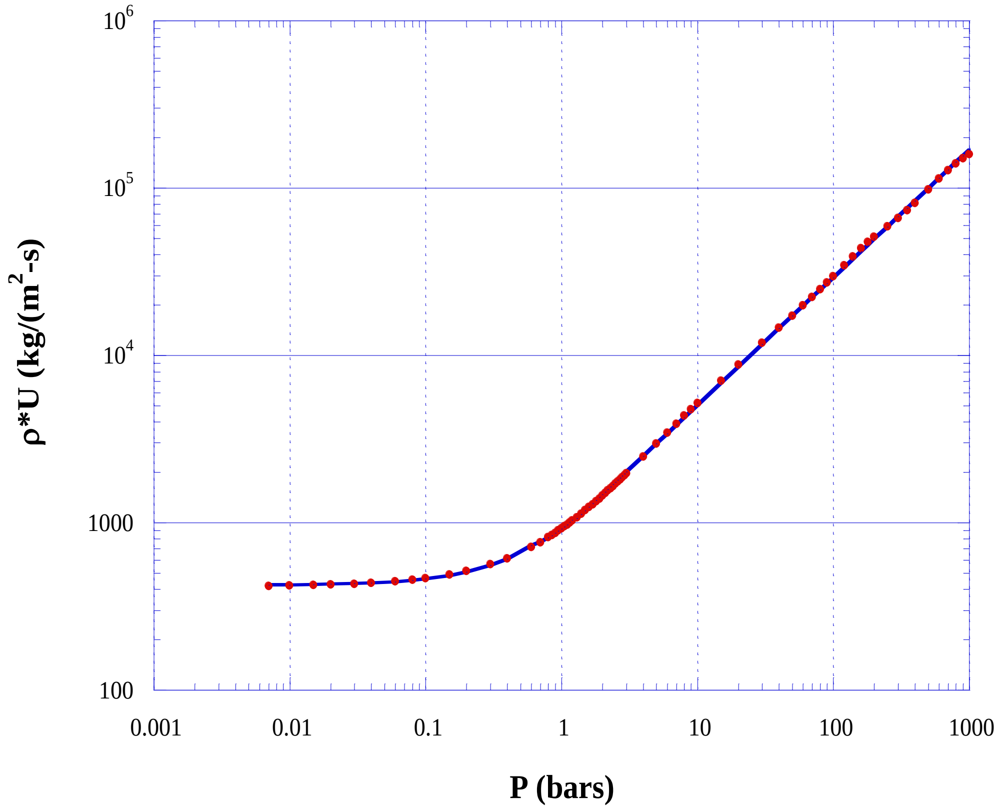
- The shockwave energy flux is defined as:

$$E = \frac{1}{\rho U} \int P_s^2 \, dt$$

ρ = Air density
U = Wave velocity
ρU = Characteristic Impedance
P_s = Overpressure
t = Time

For underwater explosions, the characteristic impedance, ρU, is nearly constant except very close to the explosion point. However, this is not the case in air. The product ρU in real air is a strong function of γ, the ratio of the specific heats.

CHARACTERISTIC IMPEDANCE (ρU) OF AIR



$P_s <= 0.6$ bars: $\rho U = 421.43\, e^{0.918\, P_s}$

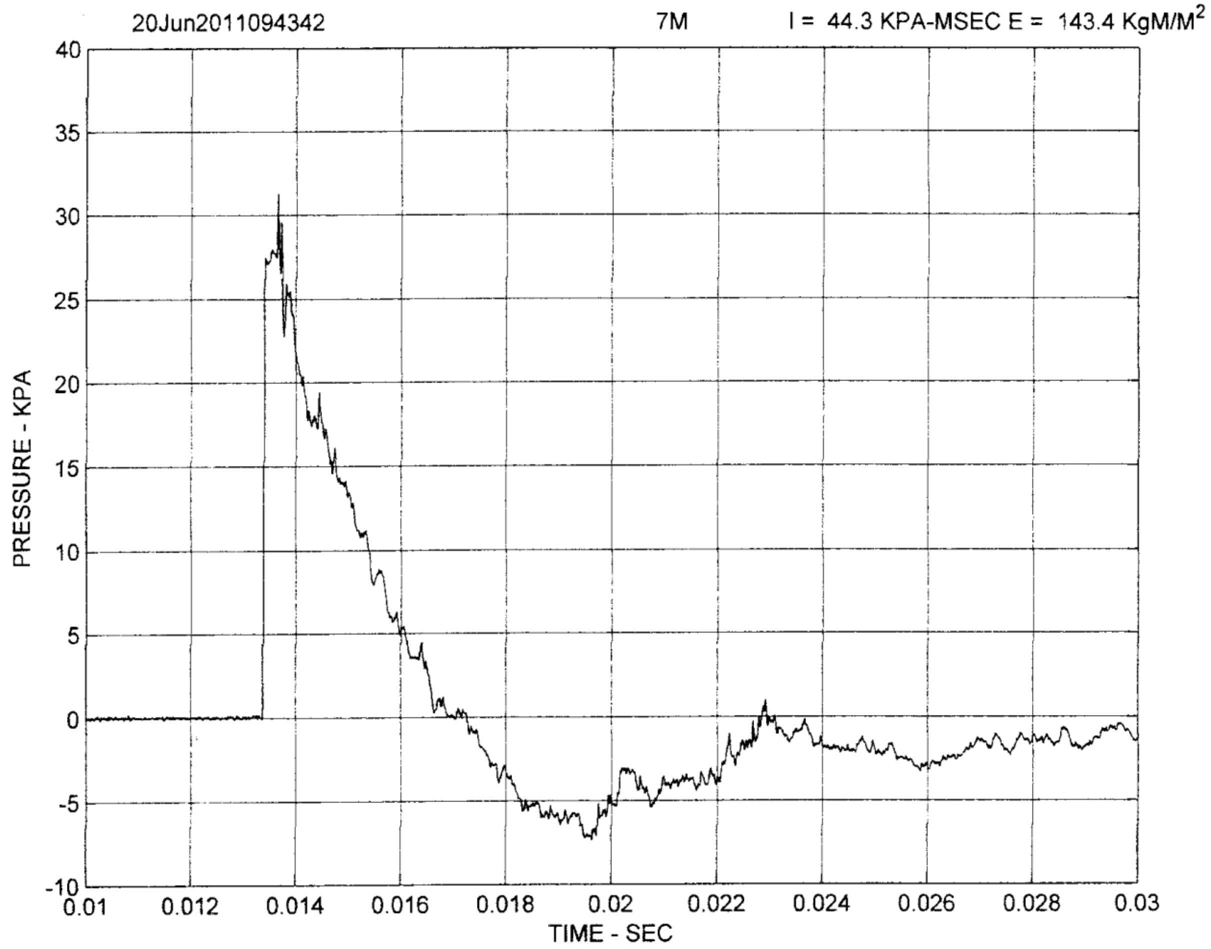
$0.6 < P_s < 1.2$ bars: $\rho U = 504.47 e^{0.6 P_s}$

$P_s >= 1.2$ bars: $\rho U = 868.86\, P_s^{0.763}$

APPLICATION

- For digitized pressure-time wave-forms, application can be accomplished in the same manner as the positive impulse—by numerically integrating the wave form
  - Impulse—numerically integrate p(t) dt from 0 to the τ, the positive phase duration
  - Energy—numerically integrate $[P(t)]^2$ dt from 0 to the τ, the positive phase duration

SAMPLE WAVEFORM



- 0.5 kg TNT
- Detonated 1m above ground
- Range = 7m

AIRBLAST WAVEFORMS

- Assume that a blast wave can be described by a Modified Friedlander Wave Form:

$$P(t) = P_s*(1-t/\tau)*e^{-at}$$

P_s = Measured peak overpressure
τ = Positive phase duration
t = Time (in same units as τ)
"a" = Modified Friedlander parameter

MODIFIED FRIEDLANDER IMPULSE AND ENERGY

- Impulse
  - If the Modified Friedlander wave form is integrated between 0 and τ, a value for the Positive Phase Impulse, I, is obtained

$$I = P_s*(a\tau + e^{-a\tau} - 1)/(\tau*a^2) \qquad (1)$$

- Energy
  - If the integral of $[P(t)]^2$ between 0 and τ is taken, a value for $E(\rho U)$ will be obtained:

$$E*(\rho U) = \{[(2*a*\tau*(a*\tau-1)-e^{-(2*a*\tau)} + 1]/(4*\tau^2*a^3)\}*P_s^2 \qquad (2)$$

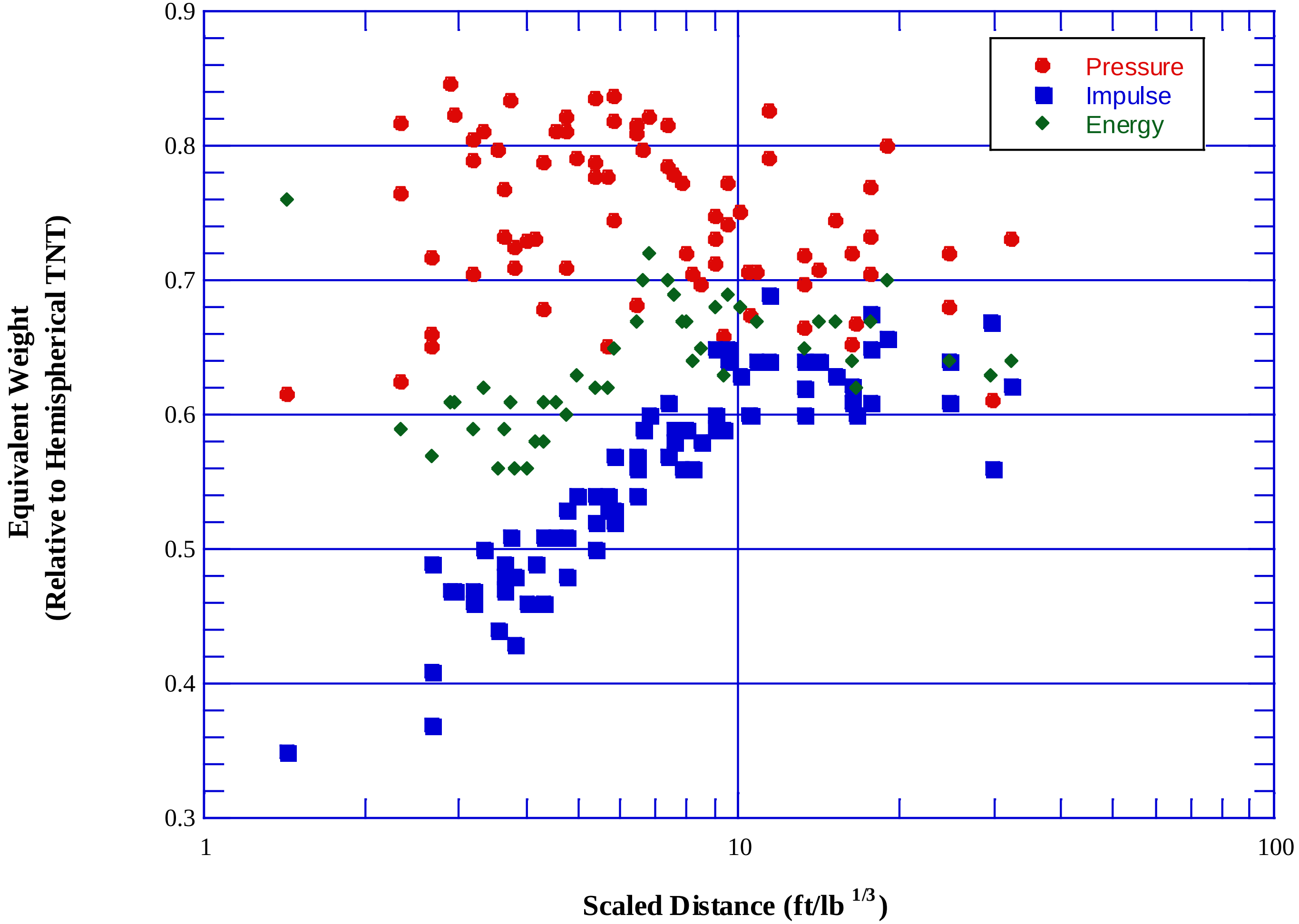
Measured values of P_s, I, and τ can be used with Equation 1 to calculate a for each (P_s, I, τ) combination

Each combination of (P_s, I, τ, a) can be used with Equation 2 to calculate $E*(\rho U)$

MISTY PICTURE EXAMPLE

- 4,684.7 ton hemisphere of Ammonium Nitrate/Fuel Oil
- Use airblast data compiled on the event to estimate the hemispherical TNT equivalent weight based on incident pressure, positive phase impulse, and energy flux

MISTY PICTURE



SUMMARY

- Conventional methodologies for calculating equivalent weight have been reviewed
- A new calculation methodology was described and its use explained through the solution of a sample problem
  - A new tool implementing the procedure was introduced
- The concept of shockwave energy as a metric for explosions in air was presented and implementation methodologies discussed
- The use of a Modified Friedlander waveform description for the observed pressure-time wave form was described and a closed form solution of the shockwave energy derived