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Shockwave Arrival Times from Operation Redwing and Operation Upshot-Knothole

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Disclaimer

Auspices Statement

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Introduction

Back in the 1940s, 50s, and 60s, 210 nuclear tests were conducted in the atmosphere. As part of the testing program, EG&G performed *shockwave arrival-time measurements* for different shots in different operations using pressure transducers at different distances from ground zero. They then developed correlations unique to each set of data. They did not attempt to correlate all data onto one curve.

As a fireball moves, material is picked up and pulled in, which is called entrainment. This extra material increases the mass of the fireball, and as the energy is spread out over a larger and larger mass, the specific internal energy of the fireball gases drops, which causes the temperature to drop as well. When the energy in the solid angle of a spherical shockwave hits the surface, it is reflected. Shortly thereafter, it catches up with the outward-moving shockwave and re-combines with it, causing it to expand at a slightly faster rate. As the shockwave grows, it approaches a hemispherical shape.

The purpose of this project is to demonstrate that the shockwave arrival-time data can, in fact, be correlated onto a single function when the shockwave time-dependent solution is modified to include a geometric factor, θ, and is corrected for an entrainment coefficient as shown in equation below.

$$d_s = C_e f\left(t_s\right), \qquad (1)$$

where d_s is the scaled distance, and

$$d_s = d\left(\frac{\rho_a}{\theta Y_{sw}}\right)^{1/3} \qquad (2)$$

t_s is the scaled time,

$$t_s = t\left(\frac{\rho_a}{\theta Y_{sw}}\right)^{1/3} \tag{3}$$

d_s vs. $f(t_x)$ is the Kinney-Graham solution, and C_e is the entrainment coefficient.

Methodology

The shockwave radius vs. time data published by Kinney and Graham[1] were plotted in the *scaled distance vs. scaled time* plane. Using the data in the original EG&G reports, the shockwave arrival time data from Operation Redwing (specifically, the shots Lacrosse and Zuni) were converted to scaled distance and scaled time and plotted on the same graph as the Kinney and Graham solution. The arrival-time data from Operation Upshot-Knothole (i.e., Climax, Annie, Harry, Grable, and Dixie) were also plotted on a similar figure.

Using a trial and error method, the scaled distance data were multiplied by a factor (which we are tentatively calling the entrainment coefficient) until the data matched the Kinney and Graham solution.

Results

The original data for Operation Redwing is shown in Figure 1 and the corrected data is shown in Figure 2.

[1] Kinney, G. F. and K. J. Graham, *Explosive Shocks in Air*, Springer Science (1985).

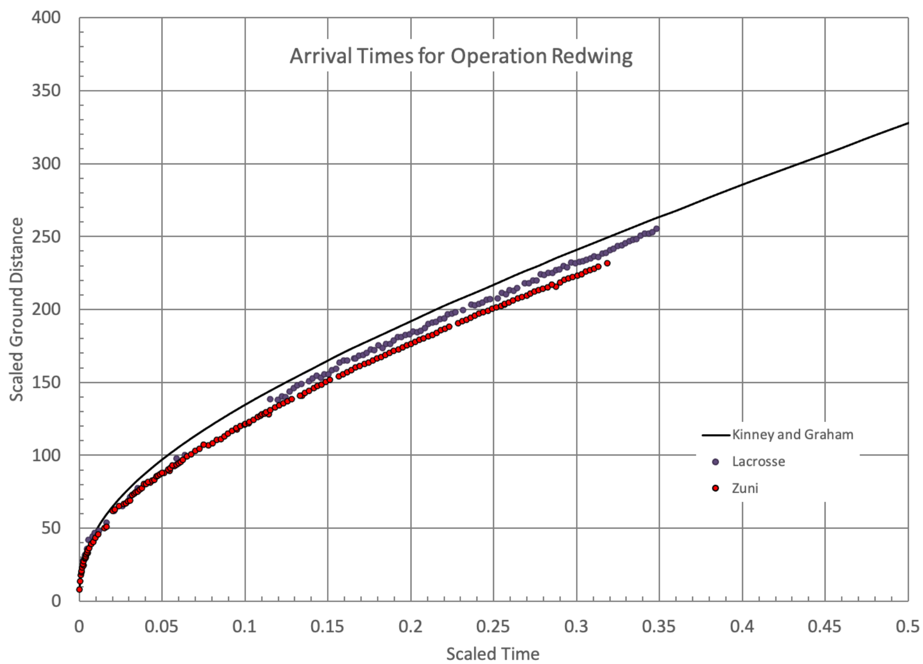

Figure 1: original Operation Redwing data.

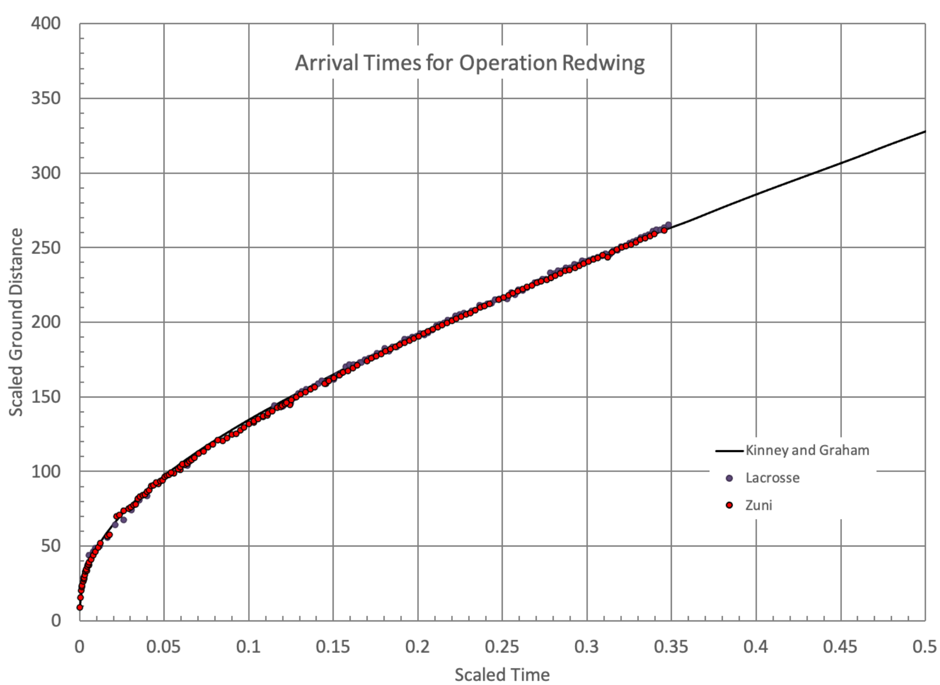

Figure 2: corrected Redwing data.

This process was repeated for Operation Upshot-Knothole with one modification. For detonations where the scaled-height-of-burst (SHOB) is greater than zero, the shockwave strikes the surface, which causes the radius of the shockwave to increase at a faster rate. To account for this effect, the scaled yield must include the time-dependent θ to correlate the arrival time data. This is accomplished as follows.

Based on the nomenclature shown in Figure 3, assuming the height-of-burst, *H*, and the distance from ground zero to the pressure transducer, *D*, is known, we can calculate θ with Equations 4 through 7.

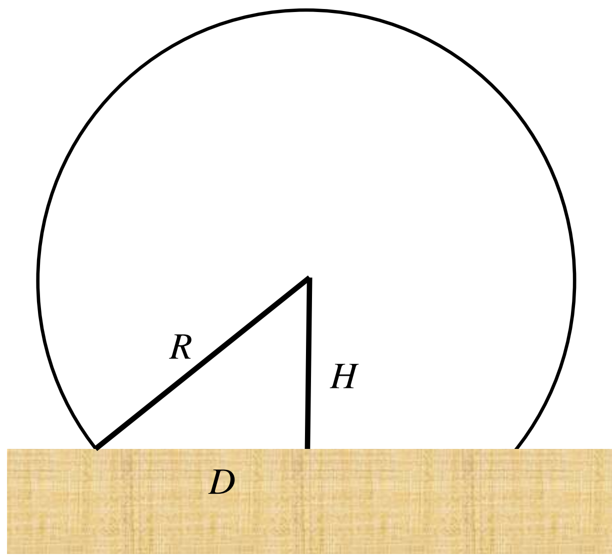

Figure 3.

$$R = \sqrt{H^2 + D^2} \tag{4}$$

$$\frac{H}{R} = \frac{H}{\sqrt{H^2 + D^2}} \tag{5}$$

$$\theta = \frac{4}{2 + 3\left(\frac{H}{R}\right) - \left(\frac{H}{R}\right)^3} \tag{6}$$

For a given *Y/ρ,* a scaled yield can be successfully calculated, and the scaled ground range can be plotted versus scaled time.

$$D\left(\frac{\rho_a}{\theta Y_{sw}}\right)^{1/3} = f\left[t\left(\frac{\rho_a}{\theta Y_{sw}}\right)^{1/3}\right] \tag{7}$$

The results for Operation UK are shown in Figures 4 and 5.

Figure 3

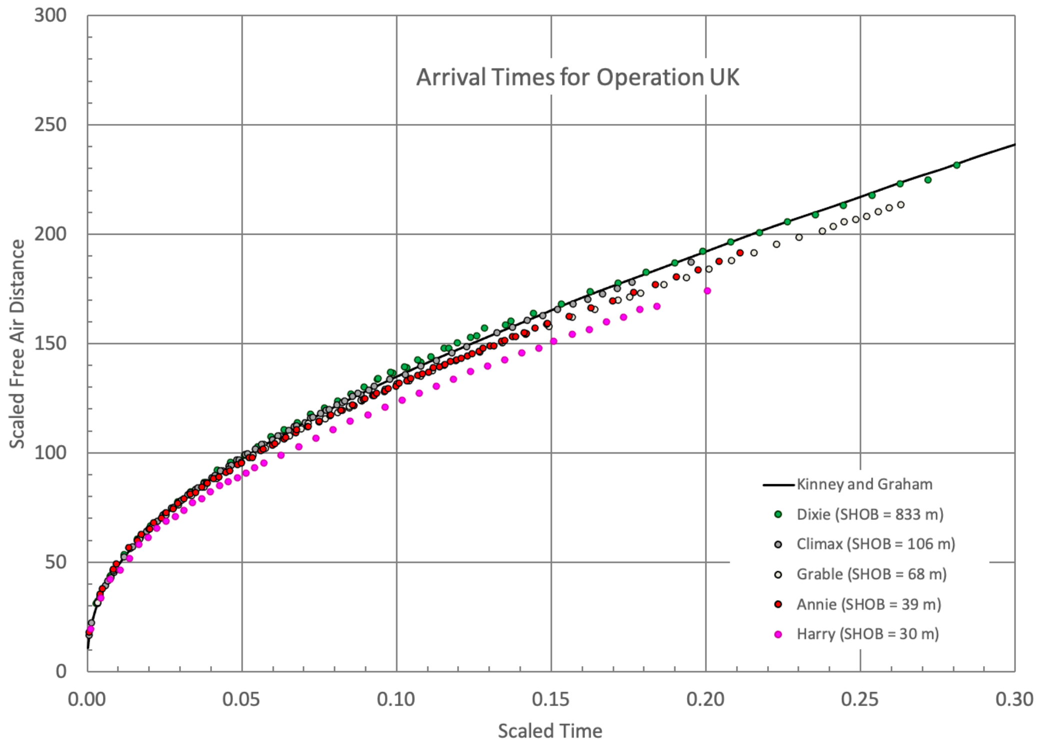

Figure 4: original UK data.

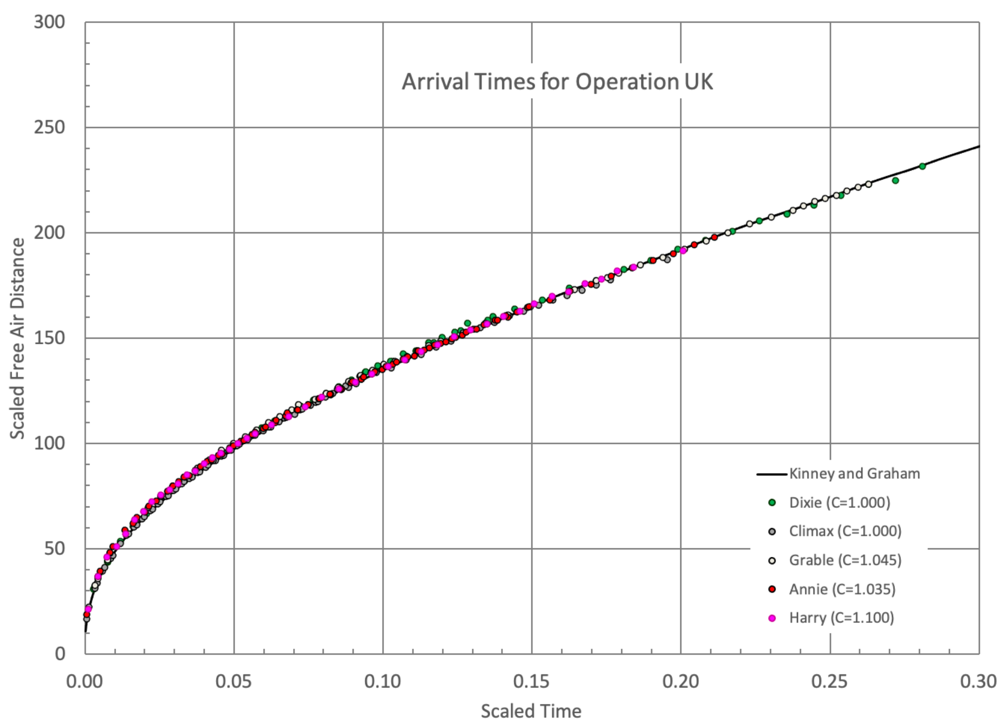

Figure 5: corrected UK data.

Table 1. Summary of Entrainment Coefficients

Shot	**SHOB(m)**	**Over**	C_e
Lacrosse	0	Coral sand	1.035
Zuni	0	Coral sand & Water	1.075
Harry	30	Alluvium	1.100
Annie	39	Alluvium	1.035
Grable	68	Alluvium	1.045
Climax	106	Alluvium	1.000
Dixie	833	Alluvium	1.000

Discussion

A summary of the entrainment coefficients derived from these data are shown in Table 1. As can be noted, the values vary as both a function of the type of surface beneath the detonation and the SHOB.

Zuni was a particularly interesting case since it was detonated on a shoreline and, as such, half the shockwave was over coral sand and the other half was over water.

Another interesting result is the comparison between Annie and Grable's entrainment coefficients. Annie's entrainment coefficient is smaller than Grable's even though Annie had a smaller SHOB. In all likelihood, this apparent discrepancy is due to the difference in the mean particle size of the soil located at ground zero for these two shots. Grable was detonated in Area 5 and Annie was detonated in Area 3. Area 5 is a dried-up lakebed and is comprised of very small particles. In contrast, Area 3 is located near the base of a small mountain range and is comprised of fine sands, medium sands, and coarse sands. The mean particle size in Area 3 is significantly larger than the mean particle size in Area 5. As such, it is not too surprising that the soil in Area 5 is easier to loft than the soil in Area 3.

Conclusions

As previously mentioned, EG&G did not take into account the time-dependent geometric factor, θ. When the shockwave radius is less than the height-of-burst, θ equals 1.0 and the shockwave is spherical. When the radius becomes larger than the height-of-burst, θ begins to change and eventually becomes asymptotic to 2.0.

The *entrainment coefficient* found for each of these detonations was obtained by trial and error. Each set of data was adjusted until it matched the Kinney and Graham solution.

Based on this preliminary study, it appears that all shockwave arrival-time data can be correlated onto a single function regardless of the height-of-burst and/or the type of surface beneath the detonation point if the time-dependent geometric factor and an entrainment coefficient are included in the function.

It is recommended that these results be validated using a state-of-the-art code such as Miranda.

References

Spriggs, G. D., *Fireball Physics*, LLNL technical report (number pending) (2020).