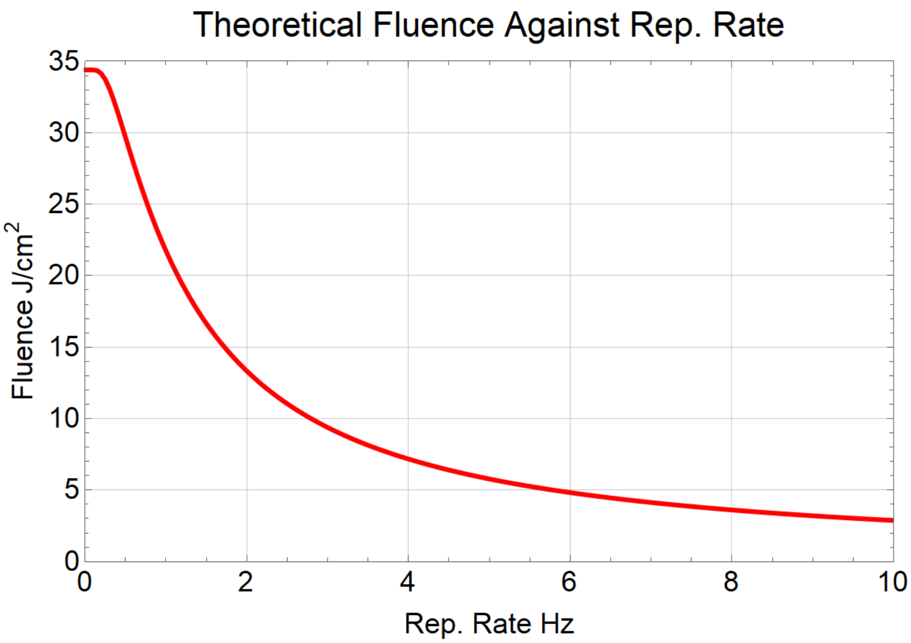

Figure 6. Critical Fluence against repetition rate for an optic with enhanced thermal diffusion.

The shape of the curve depicted in figure (5) suggests that a rule of the form (3) can be simplified even further in the right parameter regimes. It is fairly plain to see that in the case of a large repetition rate this collapses to the simple scaling rule (4) which does not require F_*

$$F_{crit}(\mathcal{R}_2) = \frac{\mathcal{R}_1}{\mathcal{R}_2} F_{crit}(\mathcal{R}_1). \tag{4}$$

When the repetition rate is very low the LIDT once again becomes equal to F_*. In the context of laser damage testing, F_* is most representative of the LIDT value obtained in the course of "1 on 1" laser damage tests whereby the LIDT is inferred from singular, high fluence pulses upon a target.[13] The general expression accounting for repetition rate, diameter ratios etc. is hence theoretically most accurate for "S on 1" tests where a target is bombarded with multiple pulses.

So called "Top-Hat" profile pulses are another common beam geometry that have somewhat different behaviour in comparison to their Gaussian counterparts. Top-hat pulses are characterised by uniform irradiation over the area of the beam. The radial profile of a top-hat pulse is compared to that of a Gaussian in figure (7).

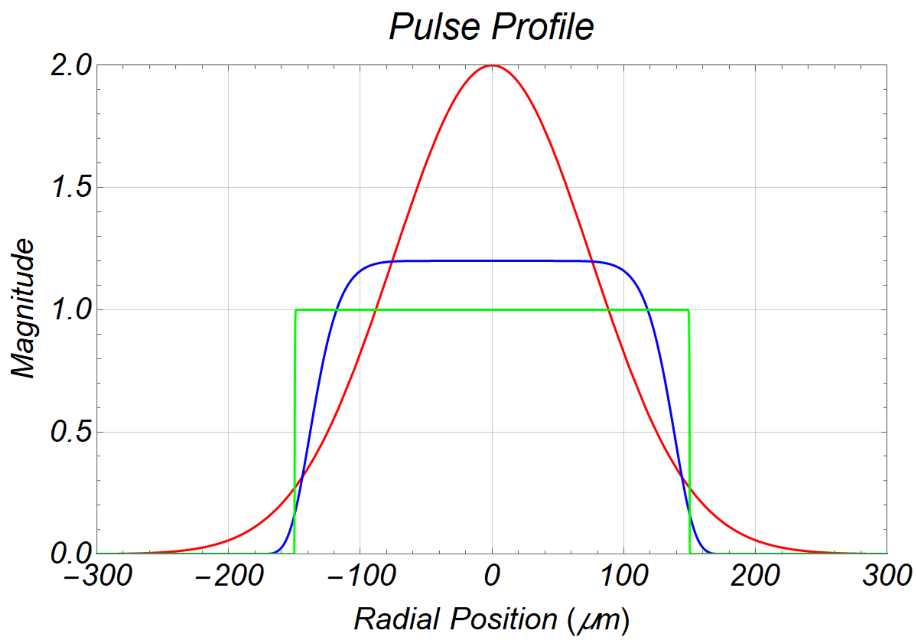

Figure 7. Radial profile of Gaussian, Super Gaussian and top-hat beams of beam diameter 300μm compared. The red curve represents a regular Gaussian pulse, the blue represents a Super Gaussian of order 10 and the green curve is an ideal top-hat profile.

Note how the top-hat has half the peak intensity but is much more spreadout than the Gaussian despite having the same power and effective optical area.

4.1 Beam To Optic Diameter Ratio

Top-hat pulse LIDT has the same form (2) and obeys similar trends to its Gaussian analogue with respect to γ. Below is a comparison of Gaussian and Top-Hat LIDT versus the beam to optic diameter ratio.

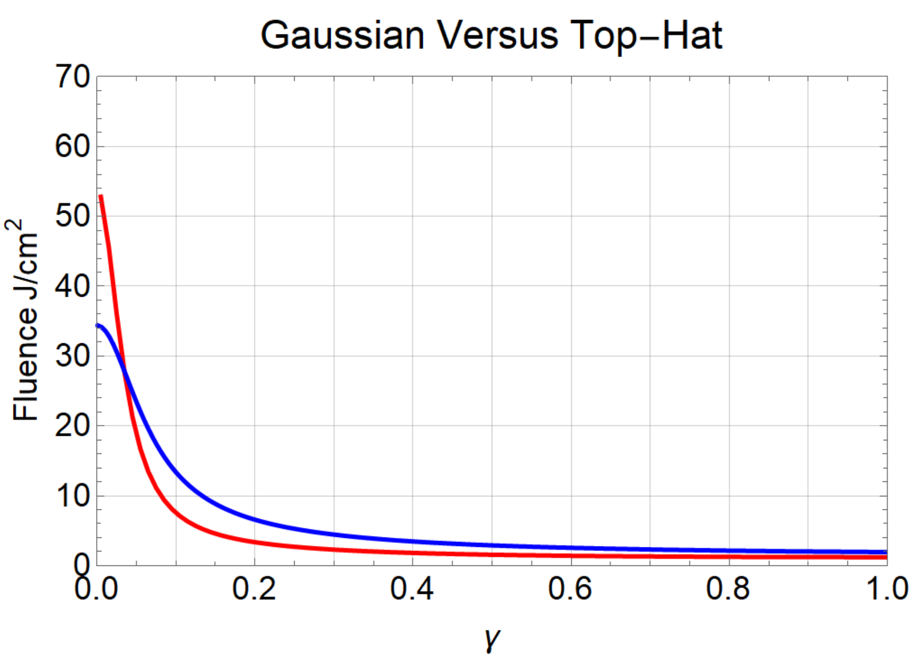

Figure 8. Critical fluence against γ for both Gaussian (blue) and Top-Hat (red) pulse structures. The Top-Hat pulse has a higher maximum critical fluence than the Gaussian case. The overall dependence of both critical fluences on γ is similar.

Studying figure (8) it is observed that generally speaking the critical fluence of the Gaussian is somewhat

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better than the Top-Hat case. This can be explained by referring to figure (7). While the peak power of a top-hat beam is around half that of a Gaussian analogue it is more uniform which is reflected in its temperature distribution. This means that heat from the centre of the optic has a harder time escaping as the gradient is not as steep. Therefore it will accumulate more heat resulting in a lower LIDT. When the beam diameter is either very small and/or the repetition rate is very low (such that damage is induced by a single pulse), the long term diffusion effects are less important and the lower overall peak intensity of the top-hat beam results in a better LIDT relative to its Gaussian counterpart. In the case of figure (8, maximum critical fluences are around 54Jcm^{-2} and 34Jcm^{-2} for the Top-Hat and Gaussian cases respectively.

5. CONCLUSIONS

The theory we have presented and discussed has interesting implications for the Laser Induced Damage Thresholds and its dependence on system parameters. Of special focus is the dependence on beam diameter and the optic geometry which is determined by the boundary conditions of the theoretical treatment of this problem, as well as the repetition rate. This model presents an alternative approach to the "defect" model for thermal laser damage which focuses on the absorption of individual tiny impurities. By considering the macroscopic nature of heat diffusion over a long period of time and accounting for the geometry of the beam it is found that thermal laser damage may be caused by a gradual build up of heat in some cases, not just damage due to an impurity absorbing a high proportion of energy froma single incident laser pulse.

It is a success of this theory that it agrees with pulse duration and wavelength scaling laws. It also suggests a very significant dependence of LIDT on the beam and optic geometries. This has implications for laser damage diameter scaling and LIDT testing. The LIDT is predicted to be lower when the entirety of an optical surface is covered by the beam compared to small spot testing but differs from the square law[12] that is used on occasion. Realistically a component will be used in conjunction with beams of comparable size outside of a performance testing environment, the theory suggests that such testing may not be very representative of thermal laser damage behaviour out in the field.

The LIDT is in addition found to be highly dependent on the repetition rate of an incident pulse train if the repetition rate is comparable to or much greater than the cooling rate. If the repetition rate is significant in comparison to the rate of cooling then relations such as (3) and (4) can be used to predict the LIDT. Otherwise a single pulse model or the given maximum critical fluence F_* shall suffice.

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