Dynamic Response of Target Development Facility Spherical Chambers

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Introduction

Fatigue analyses have been performed on proposed cylindrical reaction chambers considered for the preconceptual design of the Target Development Facility.(1) It was found that the nominal goal of 15,000 shots at a yield level of 200 MJ could be met with chambers of reasonable size. While such results were acceptable, it was of interest to consider the most efficient design possible. For sustaining completely symmetric internal pressure pulses, a spherical vessel is the optimum structural shape. Thus the mechanical response characteristics of spherical chambers have been studied to obtain the best case basis for performance comparisons with other configurations.

Analysis Summary

The model for the chamber is an elastic, relatively thin shell. The only displacement component is radial, i.e. the shell is always spherical and simply expands and contracts with time. A thin shell has a single natural frequency. A thick shell has multiple frequencies but for a moderate thickness, the fundamental frequency is much lower than any other and the contribution to stress and displacement from higher modes is negligible. The spherical shell frequency depends upon the elastic modulus, density, Poisson's ratio and shell radius, but is independent of thickness. It can be shown that for shells of interest, the vibration period is considerably larger than the pulse width of the mechanical shocks. The practical consequence of this is that the loading can be represented by its impulsive value. The procedure is more accurate than using peak pressures and also more convenient for parametric studies in which the impulsive pressure is a single additional variable.

The corresponding maximum dynamic circumferential normal stress is independent of chamber radius and is also essentially the same for steel or aluminum. The latter result is attributable to the dependence of stress on the modulus/density ratio, a factor which is nearly identical for these materials.

The stress and strain histories from each shot are cyclic with variable amplitude and thus cumulative damage criteria are used to assess chamber fatigue life. The method is based upon the ASME Pressure Vessel Code which requires the determination of the effects of the number of applied cycles of various amplitudes as compared with the number of corresponding design allowable cycles. However, instead of using ASME stress design curves, the material properties used consist of fully reversed alternating strain as a function of the number of cycles to failure. With such basic data, the general guidelines specify safety factors of two on strain magnitude or twenty on the number of cycles, whichever is more conservative. This is the only direct inclusion of a safety factor in the analysis or design. The specific fatigue life is determined using a computer code developed for this purpose. A summation procedure is applied to each strain history, assessing cumulative damage and comparing with stored data for fully reversed strain amplitude as a function of the number of cycles to failure. This identifies the number of shots permissible for a given chamber subjected to impulsive pressures which span the range of interest.

Discussion of Results

Typical first wall pressure profiles are shown in Figs. 1 and 2, based upon spherical calculations. The impulse magnitude for the 200 MJ case is approximately 110 Pa-s. The peak pressure is higher for a yield of 800 MJ but the pulse width is smaller, resulting in an impulse which is only moderately

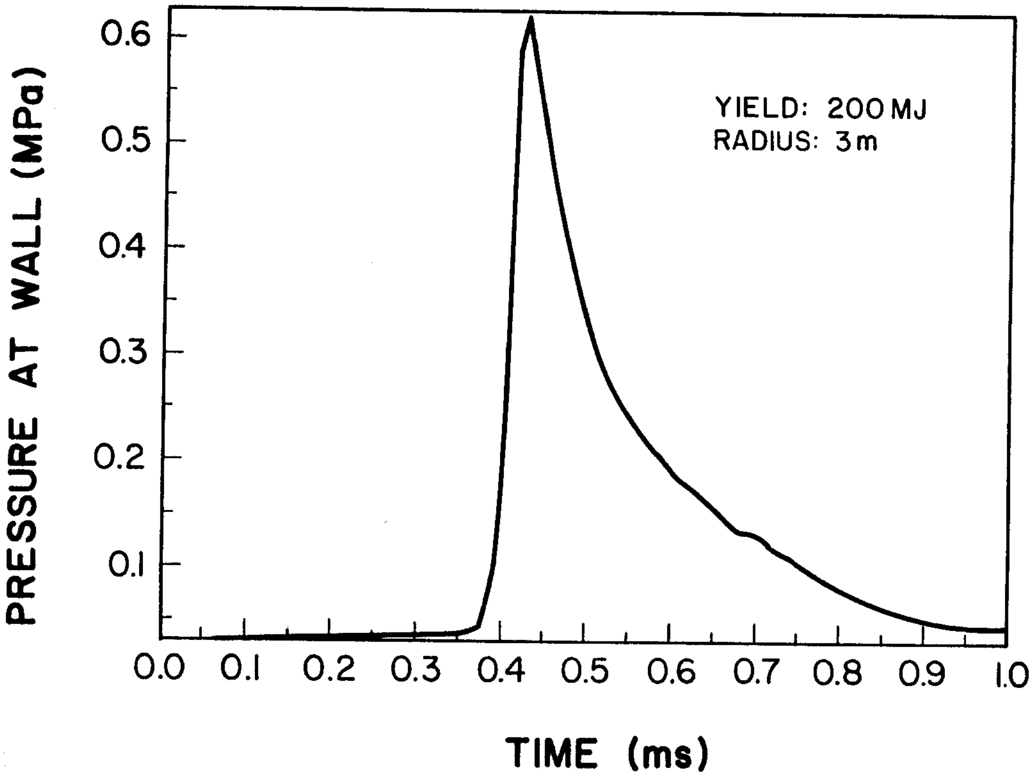

Fig. 1. Dynamic pressure at first wall, 200 MJ yield.

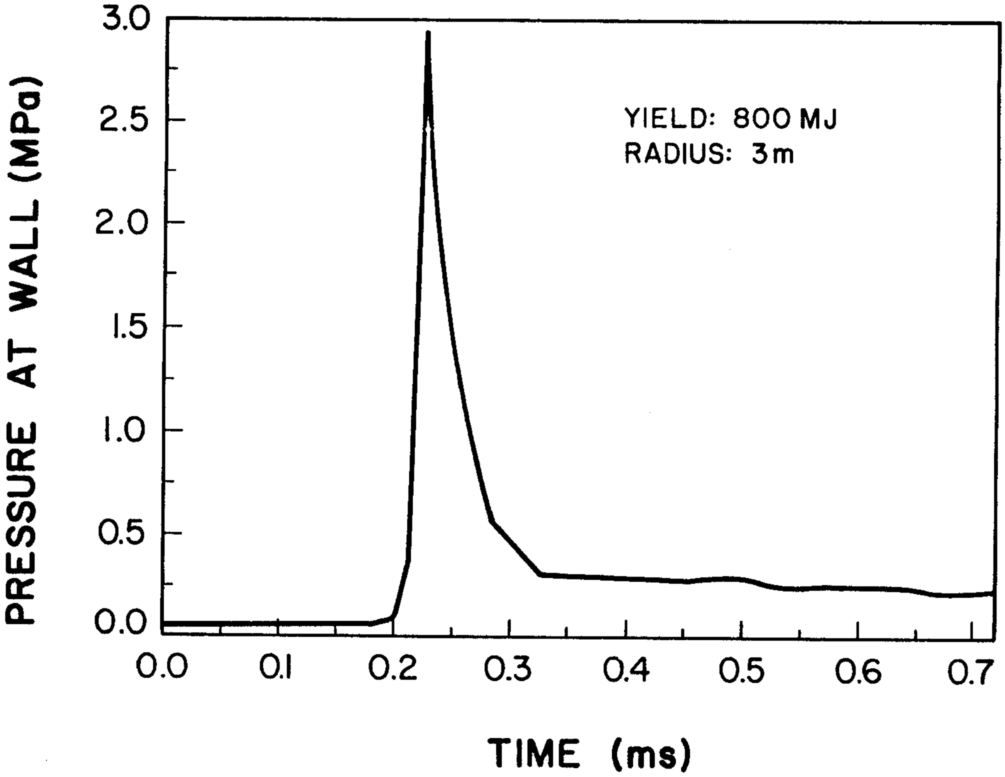

Fig. 2. Dynamic pressure at first wall, 800 MJ yield.

larger than the 200 MJ case. Corresponding maximum dynamic stresses are in the same ratio as the impulses as indicated by Fig. 3. For a constant impulsive pressure, the dynamic stress is radius-independent. However the 3 m radius is identified in Fig. 3 since the magnitude of the impulsive pressure depends upon the radius. Once again, steel and aluminum results are similar because the key material properties appear as a modulus/density ratio. Generic maximum dynamic stress results for 6061-T6 and 2.25 Cr-1 Mo spherical shells are cataloged in Figs. 4-7.

It is of interest to assess mechanical energy absorbed in the shell in response to the shock loading. The maximum strain energy (and minimum kinetic energy) would be developed in the first extreme radial excursion. Strain energy increases with increasing thickness and radius for particular stress levels. Also, because of its greater elasticity, a vessel of aluminum will contain more strain energy than one of steel under the same circumstances. In general, the strain energy levels are relatively low as shown in Figs. 8 and 9. For an aluminum chamber with a radius and thickness of 300 and 3 cm, respectively, the maximum strain energy is less than 10 kJ for a target yield of 200 MJ.

Stress histories for the base case (200 MJ, 3 m radius, 3 cm thickness) are shown in Figs. 10 and 11. The damping level of 2% is considered conservative. Corresponding response for cylindrical chambers is more complex due to interaction between modes even for axisymmetric motion.(1) In these examples the motion is assumed to be represented by a single harmonic.

Fatigue data for welded 6061-T6 aluminum and 2.25 Cr-1 Mo steel are plotted in Figs. 12 and 13. The results of running the fatigue code are shown as the life curves of Figs. 14 and 15. Terminal values on the curves at

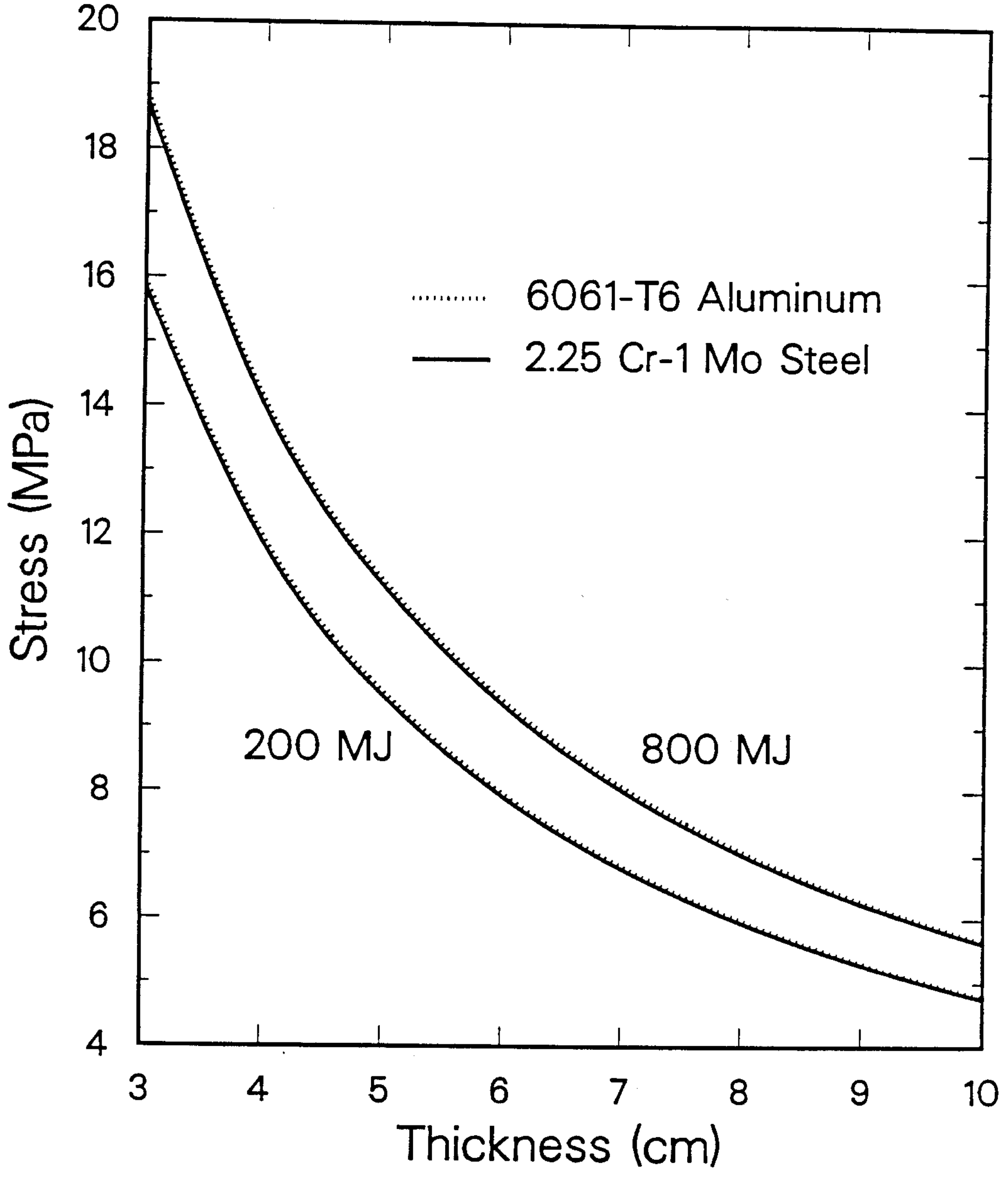

Fig. 3. Maximum dynamic stresses in 3 m spherical shells.

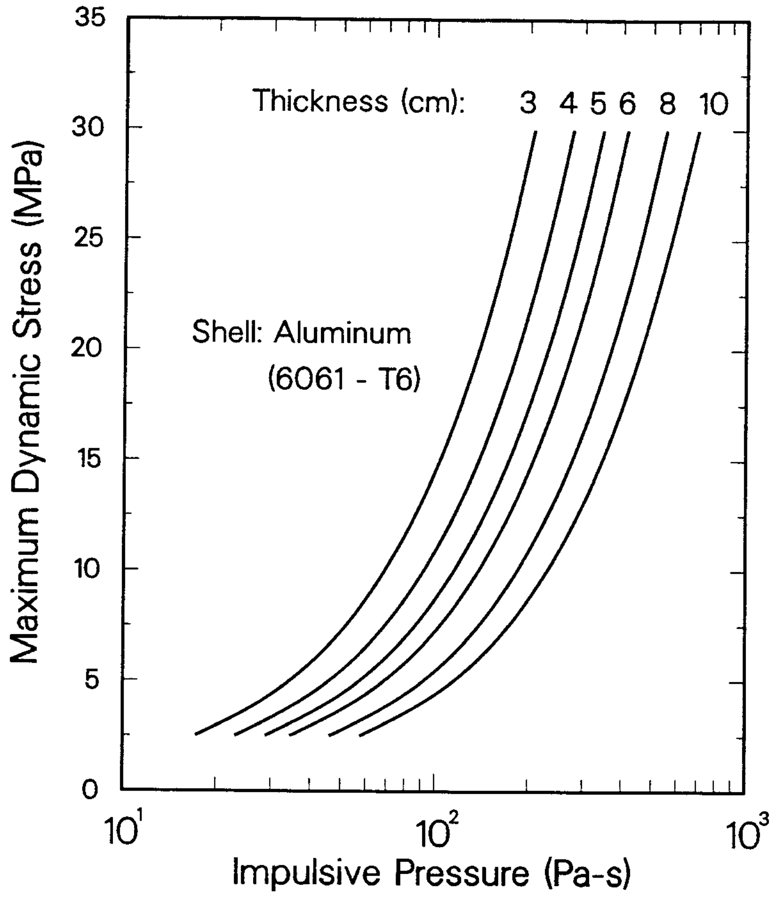

Fig. 4. Spherical shell mechanical stress from uniform impulsive pressure.

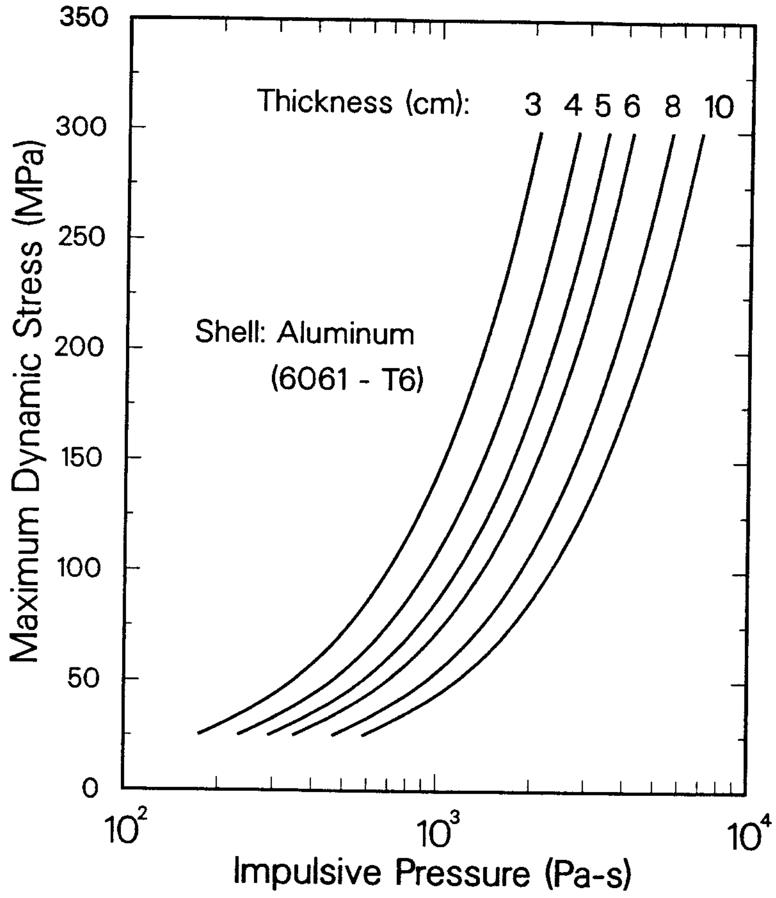

Fig. 5. Spherical shell mechanical stress from uniform impulsive pressure.

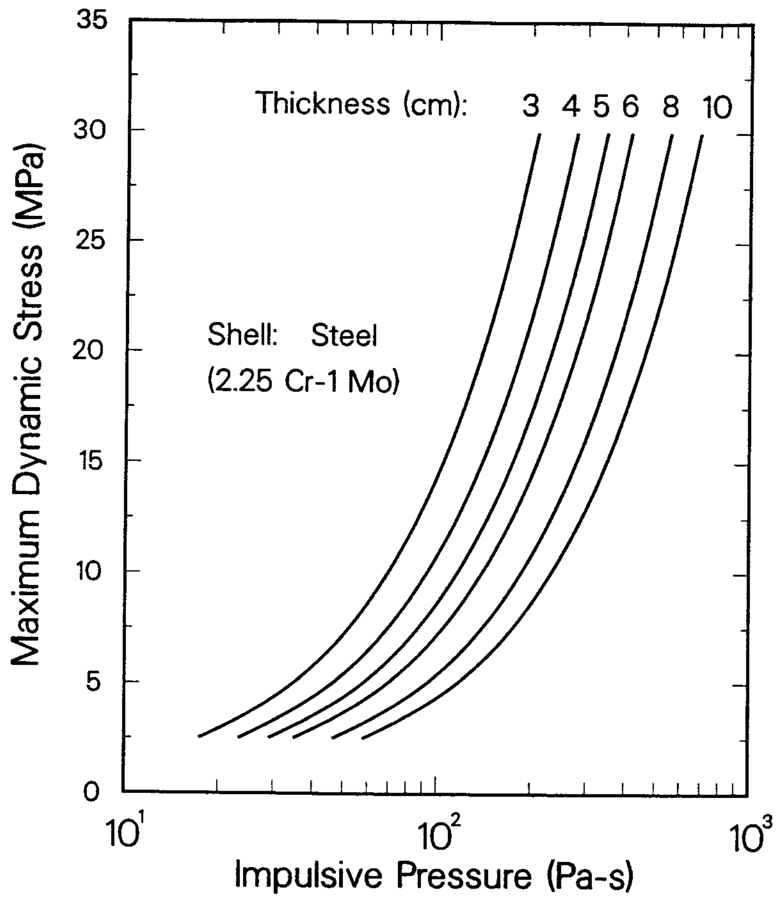

Fig. 6. Spherical shell mechanical stress from uniform impulsive pressure.

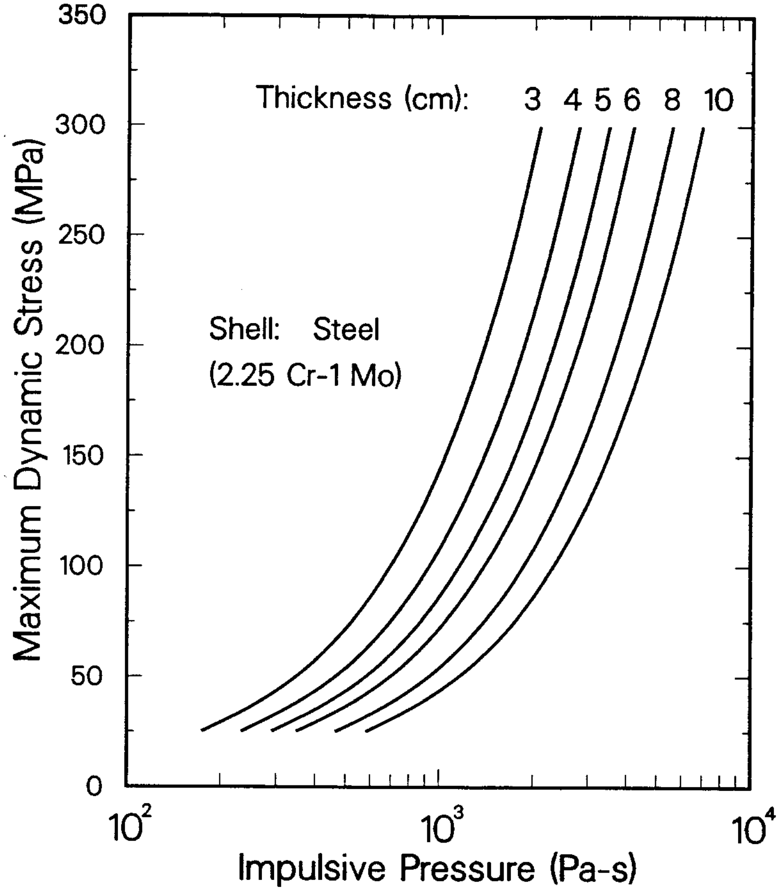

Fig. 7. Spherical shell mechanical stress from uniform inpulsive pressure.

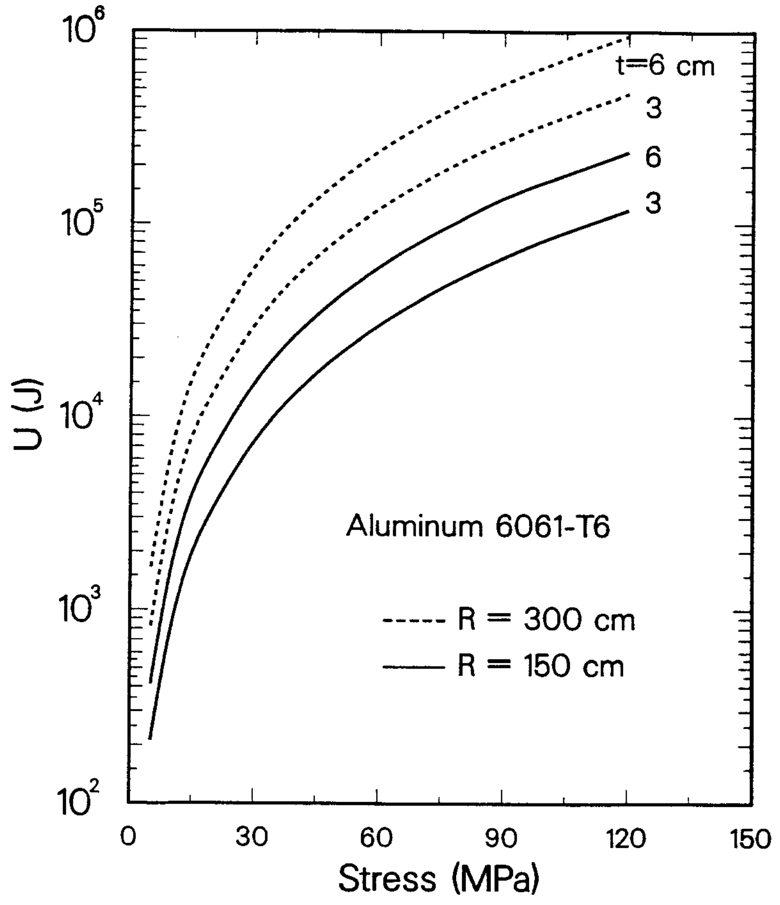

Fig. 8. Aluminum spherical shell mechanical energy.

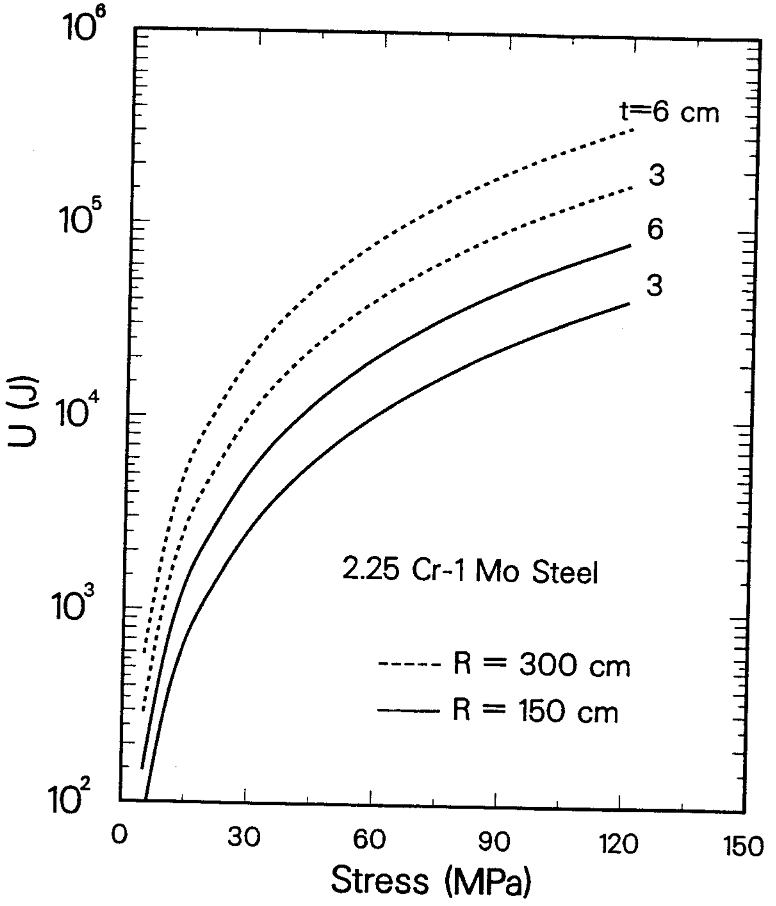

Fig. 9. Steel spherical shell mechanical energy.

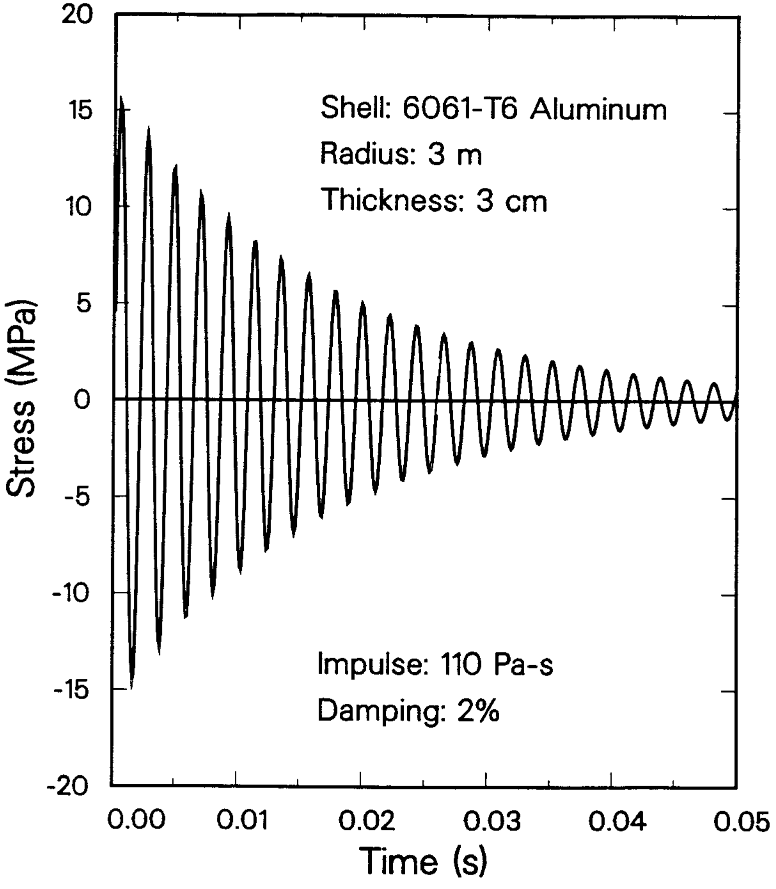

Fig. 10. Aluminum spherical shell mechanical stress history.

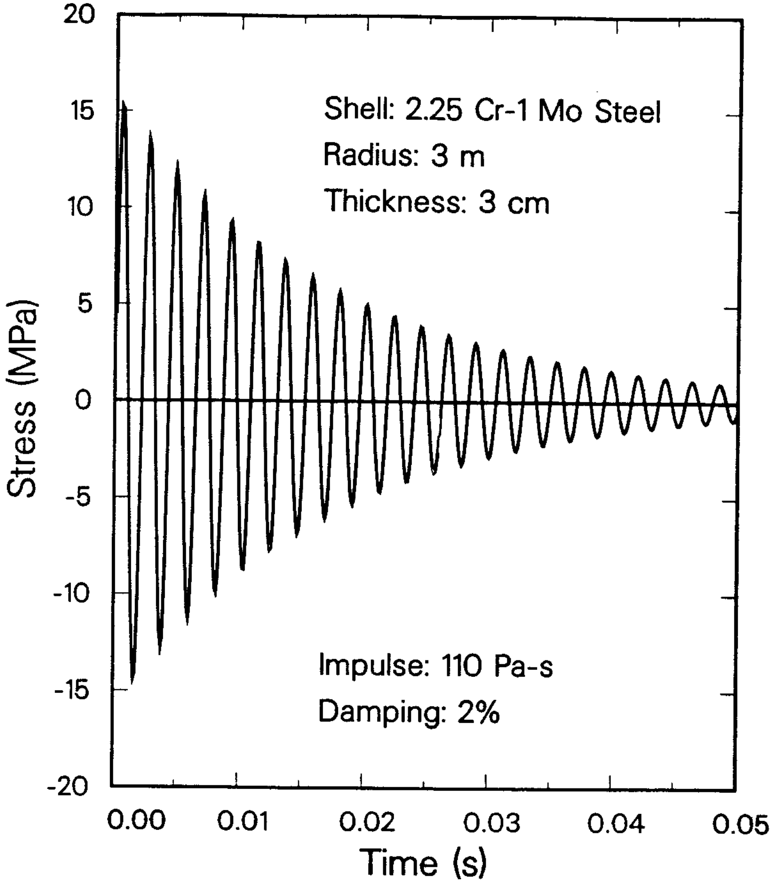

Fig. 11. Steel spherical shell mechanical stress history.

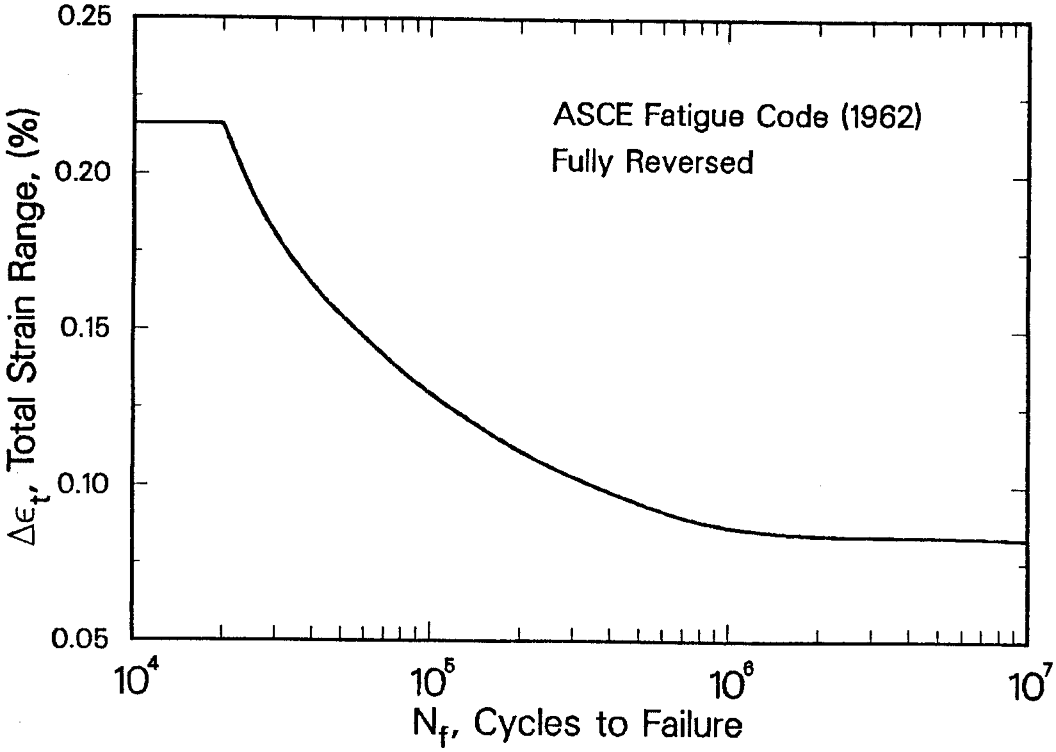

Fig. 12. Fatigue data for welded 6061-T6 aluminum.

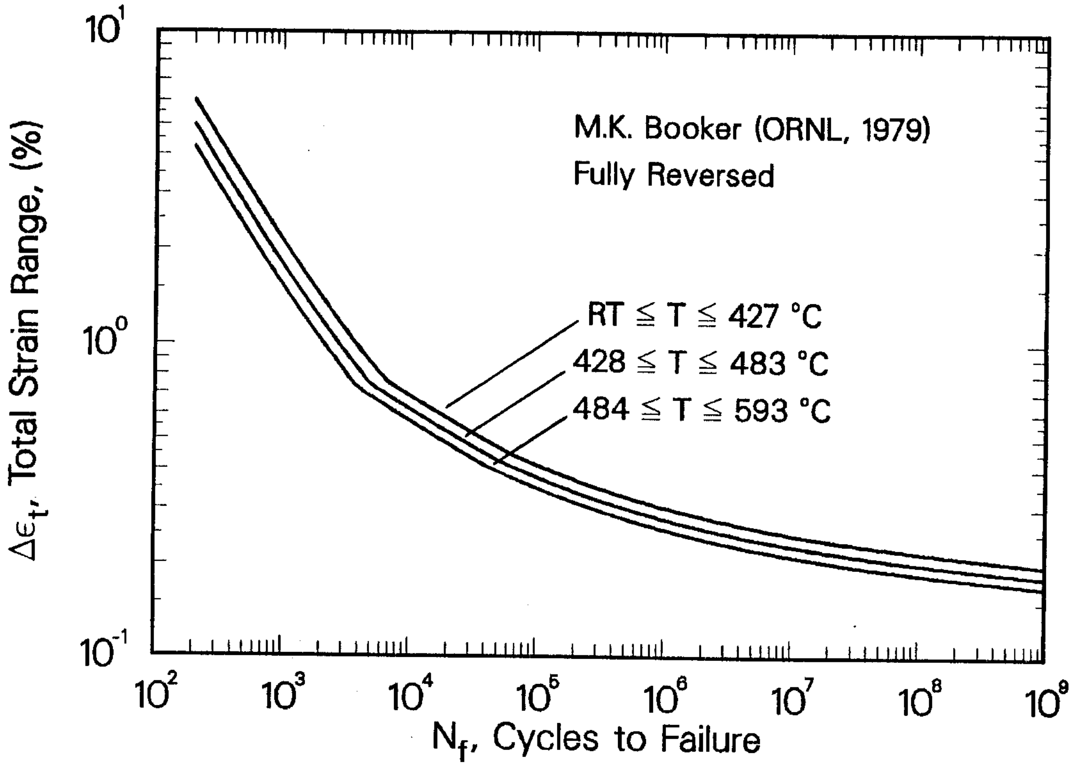

Fig. 13. Fatigue data for 2.25 Cr-1 Mo steel.

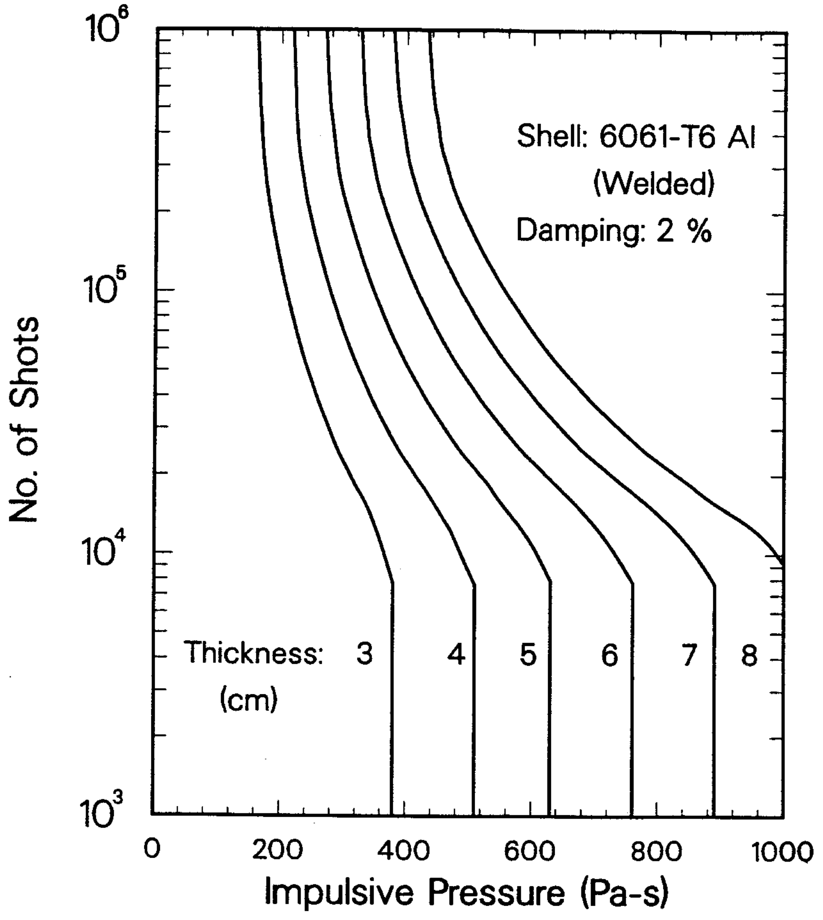

Fig. 14. Fatigue life of TDF aluminum spherical shell.

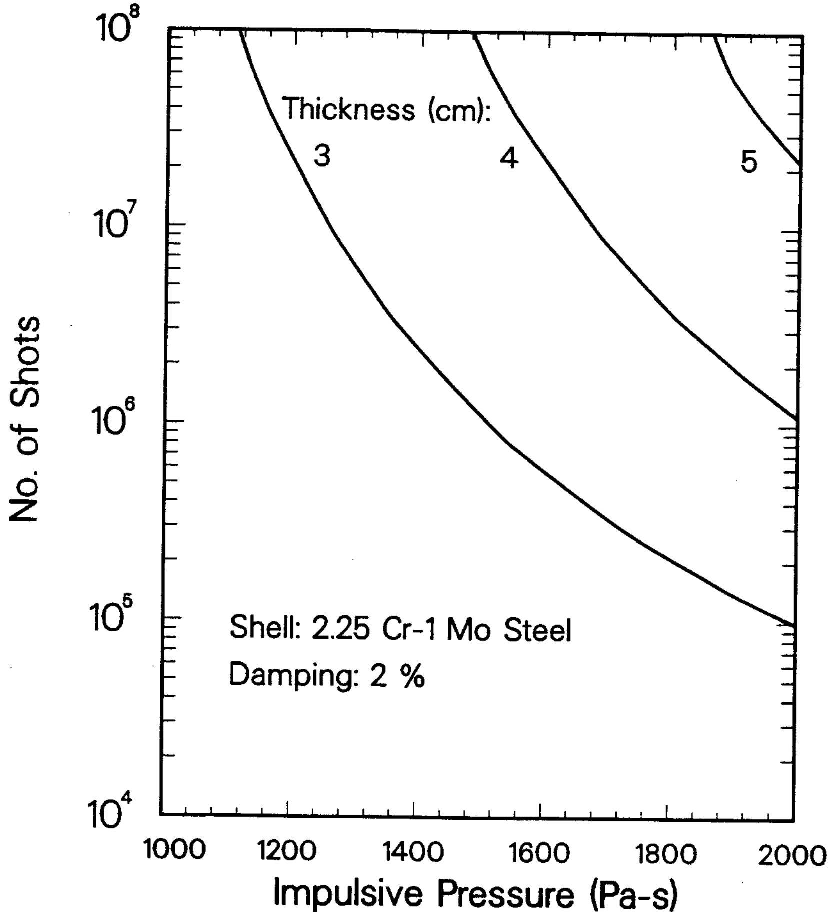

Fig. 15. Fatigue life of TDF steel spherical shell.

vertical limits identify impulsive pressures which cause dynamic yielding of the material. Results are independent of radius except that the impulsive pressure would change with radius for a given target yield.

Conclusions

Fatigue lifetimes have been evaluated for Target Development Facility spherical reaction chambers. The results for welded aluminum vessels indicate that even if the impulsive pressure at 3 m was doubled for a yield of 200 MJ, the goal of 15,000 shots could be achieved with a wall of moderate thickness. As expected, results for the steel chambers are considerably better, typically sustaining impulsive pressures an order of magnitude higher. For both alloys, the lifetime characteristics of the spherical chambers are substantially greater than the corresponding cylindrical chambers. Since the spherical chambers are capable of carrying higher loads, a more compact design with a smaller radius is possible.

Acknowledgement

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References

1. R.L. Engelstad and E.G. Lovell, "Parametric Lifetime Analysis of Cylindrical Chambers for the Target Development Facility," University of Wisconsin Fusion Technology Institute Report UWFDM-656 (Oct. 1985).