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THEORETICAL HYPERVELOCITY BALLISTIC LIMIT FOR SINGLE OR DOUBLE PLATES USING NONLINEAR MODAL ANALYSIS

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The present work deals with the original research on the use of nonlinear vibration technique to solve for the hypervelocity ballistic limit for double plates. Such structure is commonly found in typical space station design where the incoming space or man-made debris would be fragmented upon hitting the outer plate (shield) and the subsequent impact on the main wall would result in a much reduced damage of the space station or spacecraft. The existing few theoretical impact equations do not agree well with each other (Christiansen 1989). The existing computer code "bumper" used at NASA-Johnson Space Center appears to predict unconservative ballistic limit when compared with experimental data where the velocity ranges from 3 km/s to 8 km/s. Such unconservative prediction is unacceptable from a practical safe design point of view. The "bumper" code is based on Wilkinson's (1968) paper and his equations have not been improved nor modified even though they are viewed with suspicion due to lack of agreement with experiments. To make matters worse, there is not other theory which is better than Wilkinson's equation and the designers are forced to use purely empirical Nysmith (1969) or semi-empirical equations developed by Cour-Palais in 1969. The Cour-Palais equations were later modified empirically in 1989. Since the actual velocity of a space debris ranges from 10 km/s to 60 km/s and the highest experimental projectile velocity is 8 km/s (at NASA-Marshall), one is compelled to use extrapolation of existing experimental results. It is well known that extrapolation (rather than interpolation) could easily give grossly erraneous data. Since Wilkinson's equation is a purely theoretical equation based on the energy-balance mechanics concept, the extrapolation error is avoided, and when it is properly modified, it may be the only valid equation in the extremely high velocity range near 50 km/s. The purpose of the present investigation is to examine the many assumptions of Wilkinson's equation and it appears that some of the assumptions were grossly inaccurate. An attempt is made to present design charts based on the modified-Wilkinson equation so that the designer can get a "feel" of the ranges of the parameters which are of interest and "discard" a huge range of parameters, thus, significantly reducing the number of test shots required. Further discussions on the theoretical and experimental work can be found in recent memos (Abbott 1990 and Olsen 1990). The nonlinear modal analysis was discussed by the author (Hui 1990).

The analysis is based on a solution of the governing nonlinear differential equations for a plate, assuming axi-symmetric behavior using polar coordinate

$$D\nabla^2\nabla^2 W + (\varsigma)(h)\, W_{,\bar{t}\bar{t}} - (1/\bar{r})\,(F_{,\bar{r}}\, W_{,\bar{r}})_{,\bar{r}} = 0$$

$$\nabla^2\nabla^2 F = (-Eh/\bar{r})\, W_{,\bar{r}}\, W_{,\bar{r}\bar{r}}$$

where D is the flexural rigidity, E is Young's modulus, W is the out-of-plane deflection, F is the stress function, h is thickness of the main wall, ς is the density of the plate, $\bar{r}$ is the radial coordinate and ∇^2 is the differential Lagrange operator. The assumed deflection mode is:

$$w(r) = A(t)\ e^{-r^2},\ w = W/h,\ \bar{r} = (r)(2)^{1/2}$$

and this mode is more realistic than that employed by Wilkinson since it accounts for the extent of spread of the debris and it is generally accepted that the shape of the impulse should closely resemble the deflection shape at least in the very early initial response. The stress function is solved exactly (it is exact relative to the assumed deflection) and the nonlinear equilibrium is solved approximately using a Galerkin procedure. This method would predict upper bound frequencies and thus lower bound deflections. After some algebra, the nonlinear ordinary differential equation, incorporated the effect of viscous damping δ, is:

$$A(t)_{,tt} + (2\delta)A(t)_{,t} + A(t) + b^* A(t)^3 = 0$$

where $b^* = (3/8)(1-\nu^2)$ and ν is Poisson's ratio. Note that damping was not considered in Wilkinson's equation and his equation is based on quasi-static mechanics of failure as opposed to the present dynamic equations valid for extremely short duration. The inclusion of dynamic effects would give much more realistic results.

Further, the radial strain is found to be,

$$\epsilon_r(\text{at } r=0, \text{ at outer surface}) = (h/\Delta)^2\ A(t)\ (1/2)\{1 + (1/4)(1-\nu)A(t)\}$$

where is the standard deviation of the spray, the first term is the bending strain and the second term is the stretching strain.

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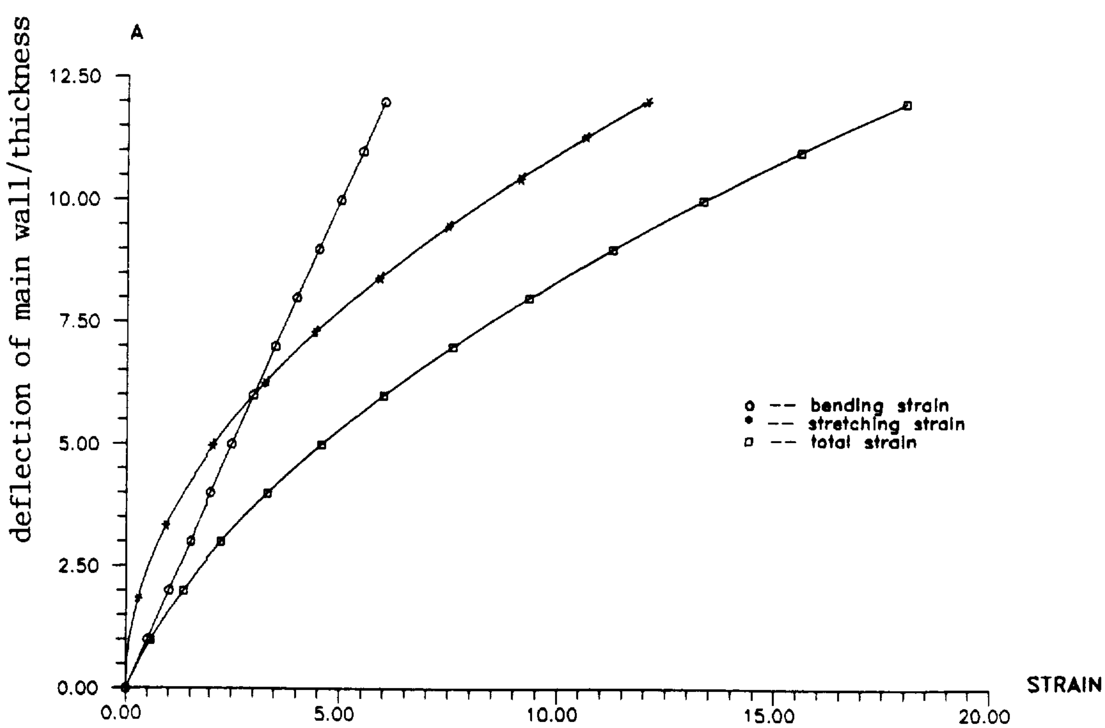

FIGURE 1

amplitude versus maximum strain of main wall

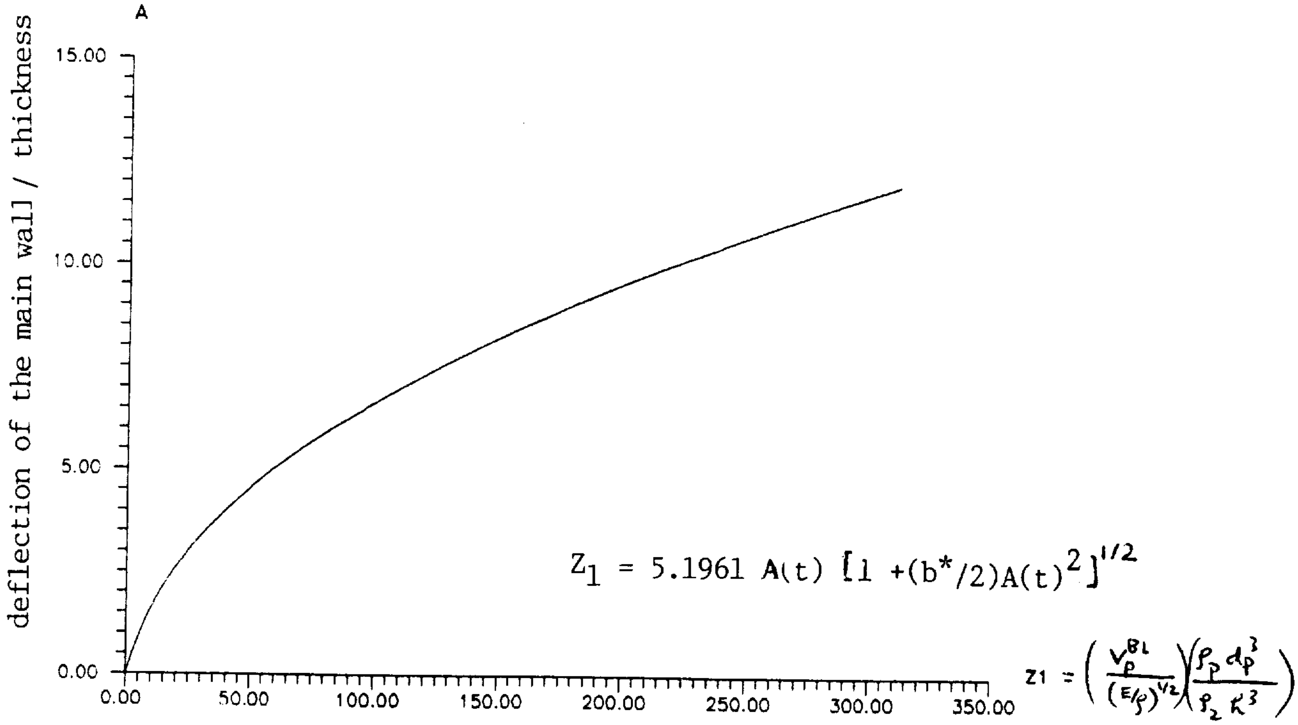

Figure 2

Amplitude versus ballistic limit velocity

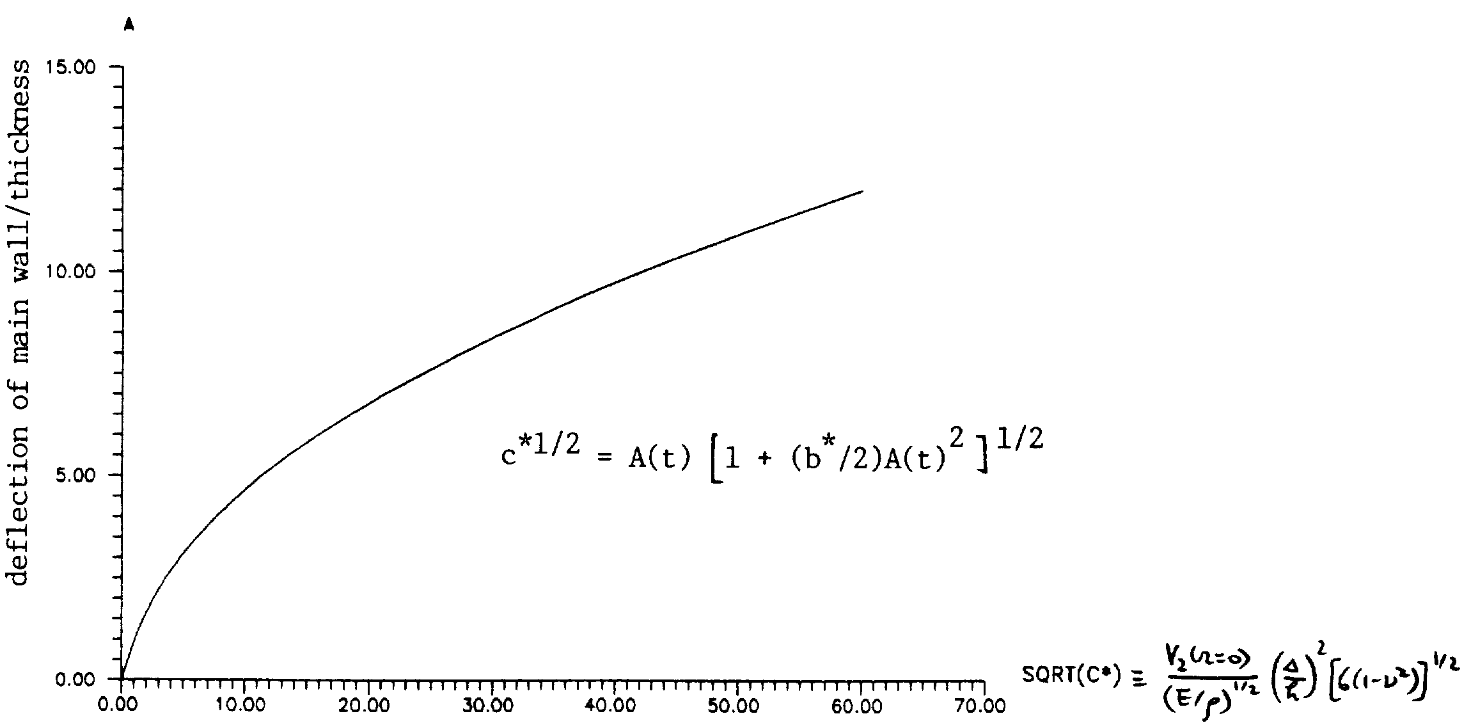

Figure 3 amplitude versus initial velocity