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Relative Magnitudes of Stresses Caused by Static and Dynamic Launch Vehicle Loads

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WHEN discussing elastic launch vehicle response to sinusoidal gusts,[1] one faces the problem of finding a suitable reference level which makes it possible for the reader to assess the seriousness of the gust response. This Note describes such a reference level based upon the comparison between the stresses occurring under static and dynamic loads. In Ref. 1, the amplitude $|\theta_N|_{\max}$ of the launch vehicle tip, resulting from passage through sinusoidal gusts, was computed for the Saturn V booster. This amplitude generates certain maximum stresses in the vehicle. By comparing those gust-induced dynamic stresses with the stresses produced by the static loads at angle of attack α, one can determine an equivalent static angle of attack giving the same stress level as the dynamic gust response.

For simplicity, the cantilever-beam approximation is used for the launch vehicle deflection under load. With the definitions of Fig. 1, one obtains

$$y'' = \partial^2 y/\partial x^2 = -[M_b(x)/EI(x)] \quad (1)$$

Using the normalized bending mode formulation, the deflection can be written[1]

$$\left.\begin{aligned} y(x) &= q(t)\phi(x) \\ \theta_N &= q(t)\phi'(x_N) \\ y''(x) &= q(t)\phi''(x) \end{aligned}\right\} \quad (2)$$

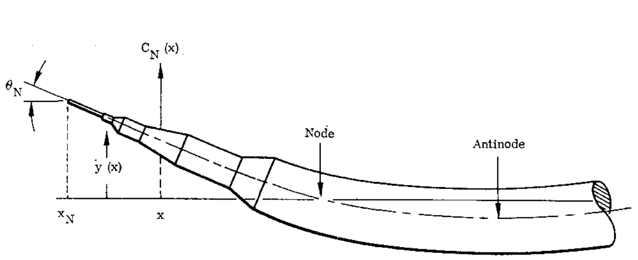

Fig. 1 Definition of elastic launch vehicle variables.

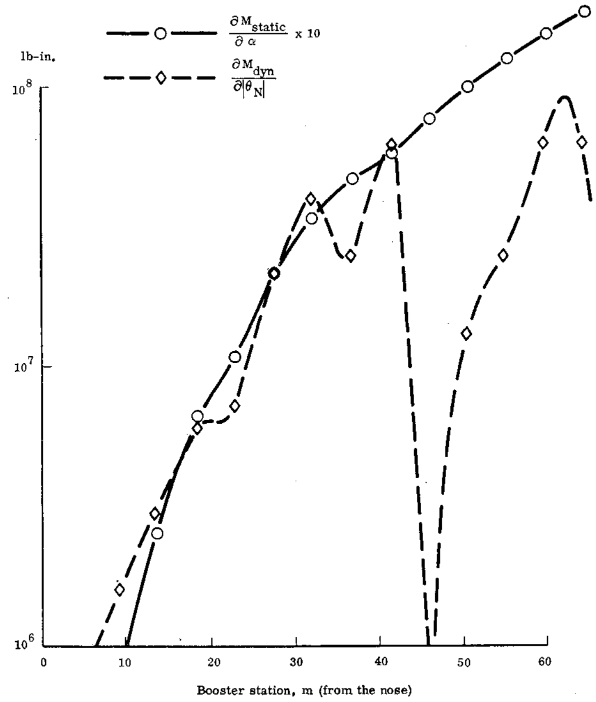

Fig. 2 Comparison of dynamic and static bending moments on Saturn V at maximum dynamic pressure, $M = 1.6$ (1st B.M.).

Thus

$$y''(x) = \phi''(x)\theta_N/\phi'(x_N) \quad (3)$$

and Eq. (1) becomes

$$|M_b(x)|_{\rm dyn} = \left[\frac{\phi''(x)}{\phi'(x_N)}\right][EI(x)]\,|\theta_N| \quad (4)$$

The static bending moment at x is

$$\left.\begin{aligned} [M_b(x)]_{\rm static} &= \left(\frac{\rho U^2}{2}\right)S\alpha \int_x^{x_N} \frac{dC_{N\alpha}}{dx}(x_N - x)dx \\ &= \left(\frac{\rho U^2}{2}\right)S\alpha \sum_{n=0}^{n} C_{N(\alpha n)}(x_N - x_n) \end{aligned}\right\} \quad (5)$$

Using the structural parameters for Saturn V, mode shape $\phi(x)$ from Ref. 2, and inertia $I(x)$ from Ref. 3, the dynamic moment amplitude $|M_b(x)|_{\rm dyn}$ defined by Eq. (4) has been computed. In Fig. 2 the dynamic moment amplitude for the first bending mode is compared with the static moment defined by Eq. (5). One can see that $|M_b(x)|_{\rm dyn}$ for $|\theta_N| = 1°$ and $[M_b(x)]_{\rm static}$ for $\alpha = 10°$ are of the same order of magnitude. The dynamic moment reaches maximum at the (first) antinode, the point of maximum curvature, and the computations need not be carried beyond this station in order to establish a reference α for the $|\theta_N|$-effect.

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