Comments

Comments on Structures Considerations in Design for Space Boosters

ERNST D. GEISSLER*
NASA George C. Marshall Space Flight Center, Huntsville, Ala.

SANDORFF presented in Ref. 1 a very interesting discussion concerning the effect of configuration geometry and size upon structural weight and control requirements. With respect to the latter, he comes to the conclusion that the control problem will be alleviated by increase in vehicle size. The author does not believe that this conclusion is realistic in a practical sense, at least not with respect to vehicles under design now and in the near foreseeable future (10^6 to 10^7 lb gross weight class).

The crucial argument is in Ref. 1 based on the equation

$$f_0 = \omega_0/2\pi = k/\rho_P L^2$$

which is derived by assuming the control frequency proportional to the angular rate of the (uncontrolled) vehicle under a given disturbance.

The (undamped) control frequency of an unstable vehicle with pure attitude control has to be selected carefully with respect to a satisfactory response to quasi-steady wind conditions that represent a major part of potential wind disturbances; the ratio of missile (total) angle of attack α_s to wind angle α_w is given by

$$\frac{\alpha_s}{\alpha_w} = 1 - \frac{c_1}{c_1 + c_2 a_0} = 1 - \frac{c_1}{\omega_0{}^2} = 1 + K$$

where

α_s = quasi-steady state angle of attack
α_w = wind angle ($\alpha_w \approx \arctan w/v$)
c_1 = $(\partial M_{\text{aero}}/\partial\alpha)(1/I_{\text{veh}})$, positive for aerodynamically stable configuration
c_2 = $\partial M_{\text{control}}/\partial\beta(1/I_{\text{veh}})$
β = control deflection[2]
a_0 = gain factor for attitude deviation[2]
b_0 = gain factor for angle of attack deviations[2] (b_0 is zero for the case of pure attitude control)
K = $c_1/[c_1 + c_2(a_0 + b_0)]$

Keeping equal response for vehicles of different size calls for K = const or $\omega_0{}^2 \backsim c_1 \backsim 1/L^2, f_0 \backsim 1/L$. The predominant emphasis on quasi-steady loads for the considered case is supported by Fig. 1, which shows curves of wind speed changes of about equal probability over various distances (scale length) with total maximum wind as parameter. These values have been obtained by statistical evaluation of actual wind measurements during several years at Cape Canaveral.

It is quite evident that larger wind changes must be expected over larger distances and that, consequently, there will be a reduction of α_w with decreasing wavelength.

For pure angle of attack control, one can reason as follows: If one again is concerned mainly with keeping the α response of the vehicle equal, one can maintain equal response to equal wind input only by maintaining a constant control frequency

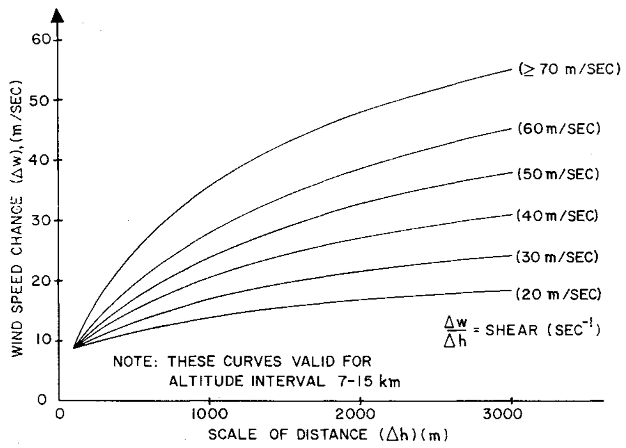

Fig. 1 Vertical wind speed change envelopes to be associated with 20 to ≥70 m/sec maximum wind magnitudes in the 7 to 15 km altitude region (Cape Canaveral, Fla.)

for similar vehicles of different size, as long as one considers the wind input frequency as equal (a function of vertical vehicle speed). Even for sinusoidal excitation, the steady-state missile response is dependent only upon frequency ratio and damping.

It should be considered, though, that such a control principle may not be practical for large vehicles, if the frequency with maximum response is fairly high, because this may involve too high inertial loading on the structure. Also, such a control may not be desirable because of the large deviations in flight path direction.

For intermediate cases with combined control input from attitude and angle of attack, the steady-state response can be made independant of the control frequency by proper selection of b_0:

$$\frac{\alpha_s}{\alpha_w} = 1 - \frac{c_1 + c_2 b_0}{c_1 + c_2(a_0 + b_0)} = 1 - \frac{c_1 + c_2 b_0}{\omega_0{}^2}$$

One also can select a combination of gain factors such as to give a desired steady-state response and optimize response for some critical gust frequency.

It is to be expected that optimum control frequencies may fall somewhere between the foregoing cases.

The intuitive argument, used in Ref. 1, that very large booster vehicles will go through the most severe aerodynamic disturbance "like the Queen Mary" will be applicable only if the angular acceleration resulting from maximum lateral wind to be expected is small enough that no angle can build up in the atmosphere which is dangerous to the vehicle structure. This eliminates, first, any consideration of load alleviation through angle of attack control, and, second, this assumption is a realistic one even for the largest vehicles under consideration (Nova) only if the vehicle is reasonably close to neutral aerodynamic stability.

It is correct that concern about large control requirement can be eliminated by designing for near neutral stability and having a structure that can withstand maximum unrelieved wind angles.

Whether a solution in this direction is preferable to the other possibility of introducing more active artificial control, thereby reducing direct wind loads but imposing eventually larger inertial control loads, remains to be seen and requires considerable more detail design work.

References

[1] Sandorff, P. E., "Structures considerations in design for space boosters," ARS J. **30**, 999–1008 (1960).
[2] Geissler, E. D., "Problems in attitude stabilization of large guided missiles," Aerospace Eng. **19**, 24–29,68,70–72 (October 1960).

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* Director, Aeroballistics Division. Associate Fellow Member AIAA.