Calculated Transient Response of an A-6 Landing Gear Door

Joseph G. Connor Jr.*
Naval Surface Weapons Center, White Oak, Md.

Abstract

TRANSIENT response to explosive shock loading of aircraft structures must be evaluated with due regard for aerodynamic and structural resonance phenomena. An explosively generated shock front, after normal reflection from a rigid surface, will be at least doubled in amplitude; the exact factor depends on the incident shock amplitude and ambient atmospheric pressure. In addition, a transient load with a short rise time may precipitate a peak response twice that caused by a slowly rising (static) load of the same amplitude. Results of static load tests on aircraft are often extrapolated to give transient loading limits without obvious consideration of the points mentioned above. Exhaustive transient loading tests or detailed calculations are seldom carried out.

This paper outlines finite element calculations made with NASTRAN on a model of an aircraft door. Good agreement was found with statically produced displacements of a full-scale sample of a landing gear door from an A-6 fighter bomber. Transient calculations were made, also with NASTRAN, and these showed that accepted transient load limits appear conservative.

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The door, shown in Fig. 1, consists of two doubly curved skins joined by 13 ribs and strengthened by several longitudinal and transverse stiffeners. It is about 5 ft long and its width ranges from about 2 ft at the forward end to about 3 ft aft. The material from which it is made is 7075-T6 aluminum alloy.

In a series of tests performed by the manufacturer,[1] outward-directed static loads were applied to the outer skin of a firmly mounted door with a hydraulic system which distributed forces to the outer skin through pressure pads glued to the skin. Loads ranging from zero through design ultimate were applied. (Design ultimate loads is 1.5 times the largest anticipated operational flight load.) From these static tests the conclusion was drawn that the maximum safe transient shock amplitude which the door can withstand is 2.5 psi inward applied to the outer skin surface.

A series of finite-element calculations have recently been performed to confirm and extend these results. For the calculations, the skins and ribs of the door were modeled with 734 triangular flat-plate elements (CTRIA2 in the NASTRAN library of elements), and the stiffeners were modeled with 110 BAR and ROD elements from the NASTRAN library. Coordinates of 313 grid points for the door model were read from drawings.[2] After the necessary constraints were applied, 1850 degrees of freedom remained in the problem.

For a biaxial stress state, the yield criterion derived from the octahedral shear stress theory[3] can be expressed in terms of an equivalent stress $\bar{\sigma}$ defined as follows:

$$\bar{\sigma} = [\sigma_1^2 + \sigma_2^2 - \sigma_1 \cdot \sigma_2]^{1/2}$$

where σ_1 and σ_2 are the principal stresses. Yield occurs when $\bar{\sigma}$ reaches the yield strength of the material in question. For 7075-T6 aluminum, the yield strength is about 70,000 psi.

Displacements and stresses were calculated for a uniformly distributed, inward-directed, 10 psi static load applied to the outer skin surface of the door. Other load amplitudes were used, but since the NASTRAN calculations are linearly elastic, responses were found to be directly proportional to load amplitude.

Calculated normal displacements of the outer skin along the fore/aft centerline of the door are shown in Fig. 2. Also shown are measured displacements produced by the design yield load applied during the static tests discussed above.[1] (Design yield load is 1.15 times the largest anticipated operational flight load.) It is evident that, from the point of view of displacements produced, the 10 psi static load in the NASTRAN calculation produces responses similar to those observed when the design yield load was applied to the door during the tests.

The largest equivalent stress produced in the door by the 10 psi inward static load was calculated to be 40,320 psi in a plate element on the inner skin. This stress is well below yield in the metal; therefore, if linearity is assumed, the door should withstand a uniform static load of (70,000/40,320) × 10, or 17.4 psi without yield.

For transient loads, reflected shock overpressure is the parameter most directly related to load-induced stresses and strains in the door. A 17.4-psi static load produces onset of

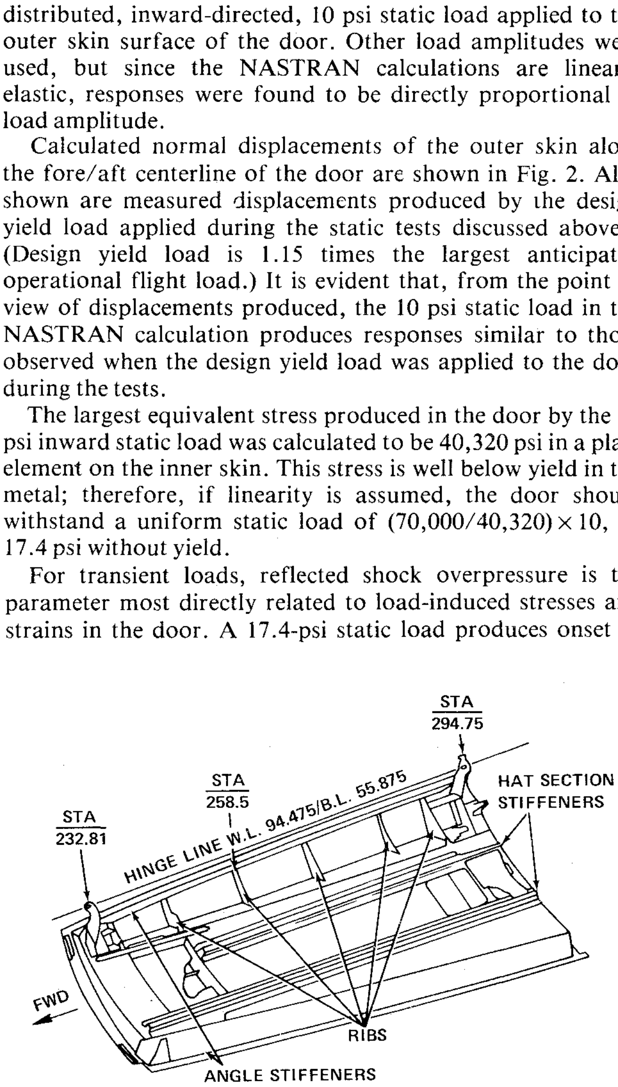

Fig. 1 Landing gear door.

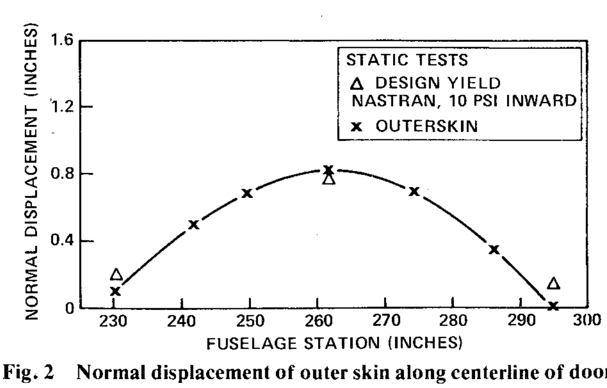

Fig. 2 Normal displacement of outer skin along centerline of door.

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*Research Physicist.

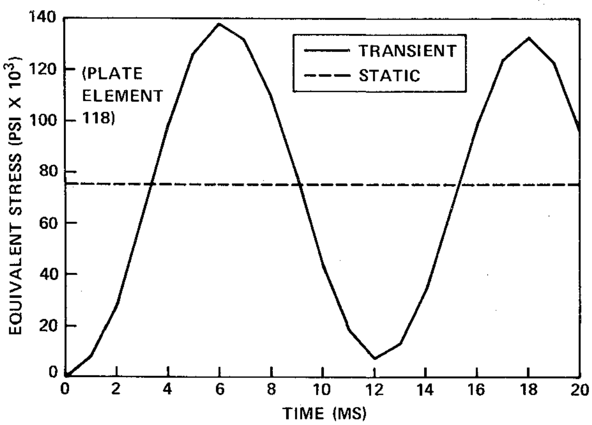

Fig. 3 Equivalent stress in most highly stressed element, 19 psi transient load.

yield in the inner skin; thus a reflected shock overpressure of that order of magnitude should severely overstress the same portion of the door because of the rapid rise of its leading edge. It happens that a 5-psi incident overpressure shock at 50,000 ft altitude produces a reflected overpressure of about 19 psi.[4]

Transient calculations were made with NASTRAN using a 19 psi transient load distributed uniformly over the outer skin surface of the door. Because of the sudden sharp pressure rise characteristic of the leading edge of a shock front, this load will produce initial peak stresses somewhat more than double those produced by the 17.4 psi static load determined above only if the structure remains elastic.

The rise time of the load was much less than 2.5% of the period of the lowest natural frequency of the structure previously calculated with NASTRAN. Thus, the load rise is effectively instantaneous. Decay of the pressure following the initial rise followed the Friedlander decay law:[5]

$$P = P_0 (1 + t/t_+) e^{-bt/t_+}$$

where

P ≡ overpressure at time t
P_0 ≡ peak overpressure amplitude
t_+ ≡ positive phase duration
b ≡ decay constant

Only the first 20 ms of structural response was calculated and printed out at 1 ms intervals. Since an earlier NASTRAN calculation had determined that the fundamental resonance of the door occurs at 89.2 Hz (for which the period is 11.2 ms), the 20 ms covered by the calculations included nearly all of the first two cycles of the resonance.

Table 1 Ranges for 9.4-psi reflected pressure from a 1-kt explosion

Altitude, ft	Side-on overpressure, psi	Range, ft
Sea level	4.2	1350
10,000	4.1	1250
20,000	3.9	1200
30,000	3.6	1180
40,000	3.3	1140
50,000	3.0	1110
60,000	2.6	1090

The transient responses ring at about 85 Hz, as expected (Fig. 3), and the largest peak stress was found to be 140,675 psi in the same element in which the maximum stress was calculated for the static loads. Thus, $(70{,}000/140{,}675) \times 19$, or 9.4 psi is the greatest reflected shock overpressure that can be withstood by the door without yielding.

Standoff distances from a 1-kiloton nuclear explosion at which a reflected shock overpressure of 9.4 psi will be produced are listed in Table 1. Note that the side-on shock overpressure required to produce 9.4 psi reflected at each altitude is somewhat larger than the accepted level of 2.5 psi.

The calculations outlined in this paper are intended to show that extrapolation of static loading test results to determine transient (shock) load limits is not straightforward. Consideration of plastic response is unnecessary since the point can be made from purely elastic considerations. In any event, NASTRAN has no capability for plastic analysis.

Plate buckling cannot be examined efficiently with NASTRAN unless there is significant curvature to the model. The landing gear door does not have a high enough degree of curvature. However, no snap-through buckling was observed during the manufacturer's static tests, so it is reasonable that plate buckling not be anticipated for the conditions considered in the present problem.

NASTRAN calculations were carried out on the NSWC/WOL CDC 6500 computer. A transient load analysis required 5,000 seconds of central processor time.

References

[1] Grumman Aircraft Engineering Corp., "Results of Removable Sections Static Tests," Report 4133.31, March 1962.

[2] Grumman Aircraft Engineering Corp. Drawings: Frame Installation – 128B11201, 128B11328, 128B11329, 128B11330, 128B11331, 128B11332; Intercostal Installation – 128B11337.

[3] Bruhn, E. F., *Analysis and Design of Flight Vehicle Structures*, Tri-State Offset Company, Cincinnati, Ohio, 1965, pp. C1.8-C1.10.

[4] Swisdak, M. M. Jr., "Explosion Effects and Properties, Part I – Explosion Effects in Air," NSWC/WOL/TR 75-116, Oct. 1975.

[5] U. S. Army Materiel Command, "Explosions in Air, Part 1," AMC Pamphlet AMCP 706-181, July 1974.