AD-754 378

SURVIVABILITY OF THE FIVE-INCH GUN LAUNCHED FINNED MOTOR CASE

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10 August 1972

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

Survivability of the Five-Inch Gun Launched Finned Motor Case

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report, 10 August 1972

5. AUTHOR(S) (First name, middle initial, last name)

Robert E. Ball

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
10 August 1972	18	2

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	NPS-57Bp72081A
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
buckling shells cylinders inelastic gun-launched projectiles						

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NPS-57Bp72081A
10 August 1972

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NOTATION

a_{max}	maximum rigid body acceleration of the projectile
E	elastic modulus in tension and compression
G	modulus of rigidity
g	acceleration due to gravity
h	thickness of the motor case
L	length of the motor case
P_b	internal axial force at the base of the motor case with bonded propellant
P_o	maximum external force acting on the base of the projectile
P_{ub}	internal axial force at the base of the motor case with unbonded propellant
r	radius of the motor case
t	time
α	duration of the breech pressure
ν	Poisson's ratio
ρ	mass density of the motor case material
σ_b	axial stress due to P_b, i.e., the axial stress at the base of the motor case with the bonded propellant
σ_{cr}	elastic buckling stress of a cylinder with a uniform axial stress
σ_{cr}/η	if the buckling is elastic $\eta = 1$, if inelastic $\eta < 1$
$(\sigma_{cr})_{inelastic}$	inelastic buckling stress of a cylinder with a uniform axial stress
σ_{cy}	0.002 compressive yield stress
σ_{ub}	axial stress due to P_{ub}, i.e., the axial stress at the base of the motor case with the unbonded propellant
ω	density

INTRODUCTION

The Naval Weapons Center, at China Lake, California, is presently in the process of developing a series of gun launched guided projectiles. Recent experimental firings of a three-inch projectile showed the structural design of the motor case to be inadequate since the case buckled severely as the projectile passed through the gun barrel. The author was asked to perform an analysis of the motor case subjected to the launch environment to determine the cause of failure. That analysis and its results are presented in Reference 1. The essential conclusions were:

1. The dynamic effects of the launch are insignificant and the case responds to the breech pressure as if the pressure were applied in a static sense, i.e., the maximum internal axial load in the case can be computed on the basis of the mass distribution and the maximum rigid body acceleration of the projectile.
2. The loading is not impulsive, i.e., it is on the case for a sufficient length of time such that the shell will collapse if the applied load equals the static buckling load of the case.
3. Approximately 80% of the propellant inertial load is carried by shear along the case when the propellant is bonded.
4. The case will buckle inelastically due to the axial load caused by the launch.
5. If the obturator cracks, 10-20% of the breech pressure acting as a lateral pressure is sufficient by itself to cause elastic buckling.
6. The predicted buckling mode for axial load and for lateral pressure is the same and is essentially identical to the observed buckled shape of the launched projectile.

This report contains the results of a similar analysis performed on a five-inch motor case. A parametric study is made with the thickness of the case, the maximum launch acceleration and the bond of the propellant as the variables. The lateral pressure considered in Reference 1 is not considered here due to the improved obturator design. The results of the study are presented in the form of survivability curves with the thickness, acceleration, and bonding condition as the independent variables. The engineer can determine the survivability of a case by selecting a value for each of these three parameters and examining the curves.

DESCRIPTION OF THE FIVE-INCH PROJECTILE

The casing is 4130 steel alloy heat treated to 200 ksi. From MIL-HDBK-5A, Feb. 8, 1966:

Elastic modulus in tension and compression, $E = 29 \times 10^6$ psi

Modulus of rigidity, $G = 11 \times 10^6$ psi

Poisson's ratio, $\nu = 0.32$

Density, ω = lbs/in.^{3}

0.002 Compressive Yield Stress, $\sigma_{cy} = 198{,}000$ psi

Total round weight: (from data sheet, L. R. 10-20-71)

Guidance Head	20.0 lbs	forward = 60.0 lbs
War Head	40.0 lbs	
Motor Case*	17.9 lbs	motor = 36.5 lbs
Propellant	18.6 lbs	
Fin Assembly	8.5 lbs	aft = 8.5 lbs
	105 lbs	

Length, L = 20 in.

Radius, r = 2.5 in.

Thickness, h = 0.19 in., 0.15 in., 0.12., 0.10 in., 0.09 in.

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*Based upon a thickness of 0.19 in.

DESCRIPTION OF THE EXTERNAL LOAD

The external load on the projectile is the breech pressure at the base of the projectile.* A typical time history of the breech pressure on the five-inch projectile (h = 0.15 in.) is shown in Figure 1. Thus, a_{max}, the predicted maximum rigid body acceleration of the projectile, is

$$a_{max} = \frac{\text{Maximum Force}}{\text{Total Mass}} = \frac{(34\text{ksi})(0.9424)(\pi)(2.5\text{ in.})^2}{105\text{ lbs/g}}$$

$$= 6{,}000\text{ g}$$

The factor 0.9424 converts breech pressure to base pressure (data sheet for five-inch projectile, L.R., 10-20-71) and g is the acceleration due to gravity.

The maximum acceleration used in the following analysis is 6,000 g for the 0.19 in. thickness case and 7,000 g for all the thicknesses.

*The obturator design has been modified to prevent cracking; and, hence, there is no lateral pressure on the case.

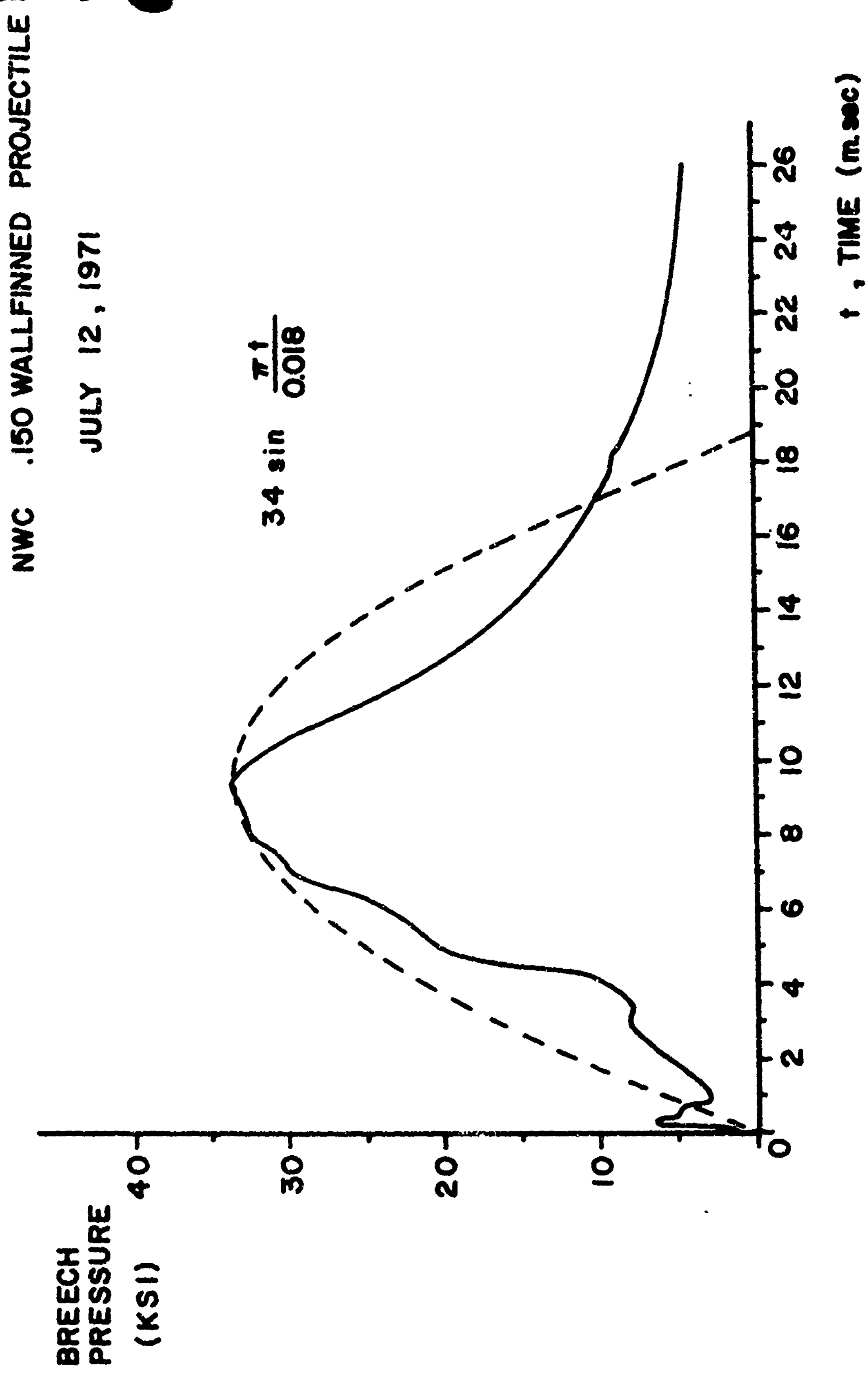

FIGURE I. BREECH PRESSURE vs TIME

DETERMINATION OF THE INTERNAL AXIAL FORCE

The results of the analysis presented in Appendix A of Reference 1 indicated that if the loading function on the case is of the form $P_o \sin \frac{\pi t}{\alpha}$, $0 \leq t \leq \alpha$, and if the "natural frequency" of the case $\sqrt{\frac{E}{\rho}} \frac{\pi}{L}$, is considerably higher than $\frac{\pi}{\alpha}$, then the dynamic effects are negligible, i.e., the shell responds in a static sense to the changing load.

A half sine wave has been superimposed on the loading history in Figure 1. A comparison of the two curves reveals that the loading curve is approximately a half sine wave with a frequency (π/0.018) rad/sec. For the five-inch case with L = 20 in.

$$\sqrt{\frac{E}{\rho}} \frac{\pi}{L} = \sqrt{\frac{29 \times 10^6 \times 386}{0.283}} \frac{\pi}{20} = 9.95 \times 10^3 \pi \text{ rad/sec}$$

which is considerably higher than π/0.018. Hence, the dynamic effects will be neglected in this first order engineering analysis*.

The internal axial force in the motor case is due to the mass forward of the case, the mass of case, and some of the mass of the propellant. Assuming all of the propellant mass loading is carried by shear on the case, the internal axial force at the base of the case P_b is

Axial Force (bonded propellant)

a_{max}	6,000 g	7,000 g				
h	0.19 in.	0.19 in.	0.15 in.	0.12 in.	0.10 in.	0.09 in.
P_b	580 kips	675 kips	650 kips	630 kips	615 kips	610 kips

The stress due to P_b is

$$\sigma_b = \frac{P_b}{2 \pi r h}$$

---

* The loading curve shown in Figure 1 can be expressed in a Fourier Sine series. The magnitude of the higher harmonics in that series will depend upon how close the loading function is to a single half sine wave. The higher harmonics have higher frequencies, and hence, the case will respond dynamically to these higher harmonics. A study of the significance of these higher harmonics will be made in the near future.

Hence

TABLE 1

Axial Stress (bonded propellant)

a_{max}	6000g	7000 g				
h	0.19 in.	0.19 in.	0.15 in	0.12 in	0.10 in.	0.09 in.
σ_b	194 ksi	226 ksi	276 ksi	334 ksi	392 ksi	431 ksi

For the unbonded propellant, none of the propellant mass is carried by the case. Thus, P_{ub}, the force at the base with unbonded propellant is

Axial Force (unbonded propellant)

a_{max}	6000g	7000g				
h	0.19 in.	0.19 in.	0.15 in.	0.12 in.	0.10 in.	0.09 in.
P_{ub}	467 kips	545 kips	520 kips	500 kips	485 kips	480 kips

and the stress σ_{ub} is

TABLE 2

Axial Stress (unbonded propellant)

a_{max}	6000g	7000g				
h	0.19 in.	0.19 in.	0.15 in.	0.12 in.	0.10 in.	0.09 in.
σ_{ub}	157 ksi	183 ksi	220 ksi	265 ksi	308 ksi	339 ksi

DETERMINATION OF THE STATIC BUCKLING

LOADS OF THE FIVE-INCH CASE

The results of Reference 1 and of the preceding analysis indicate that the motor case can be designed using standard procedures for estimating the static buckling strength of shells. The elastic buckling stress σ_{cr} for the condition of uniform axial compression* was determined using the formula presented in Reference 2, page 528. The result is

Elastic Buckling Stress

h	0.19 in.	0.15 in.	0.12 in.	0.10 in.	0.09 in.
σ_{cr}	530 ksi	417 ksi	334 ksi	278 ksi	250 ksi

Since σ_{cr} is much larger than σ_{cy}, the buckling is inelastic, and the predicted elastic buckling loads are invalid. When estimating the inelastic buckling stress $(\sigma_{cr})_{inelastic}$ from the chart of Reference 2, page 704, we encountered some difficulty since σ_{cr} = 530 ksi was beyond the limit of the chart. Consequently, the maximum value of σ_{cr}/η of 400 ksi was used for $\sigma_{cr} > 400$ ksi. Converting the inelastic buckling loads of page 704 to 200 ksi h.t. using the same procedure as described in Appendix D of Reference 1 gives

TABLE 3

Inelastic Buckling Stress

h	0.19 in.	0.15 in.	0.12 in.	0.10 in.	0.09 in.
(σ_{cr}) inelastic	182 ksi	182 ksi	178 ksi	175 ksi	174 ksi

* The axial load in the case is not uniform but varies along the length due to the distributed mass of the case and propellant. The assumption of uniform axial force is conservative and also allows the use of the charts of Reference 2. A varying load requires a computer program. This was considered in Reference 1, page 11, loading condition 1b. Further studies of this effect are planned in the near future.

CONCLUSION

The maximum value that σ_b (or σ_{ub}) can have is that given by $(\sigma_{cr})_{inelastic}$ if the case is to survive the launch. If σ_b (or σ_{ub}) is greater than $(\sigma_{cr})_{inelastic}$ then the case will buckle inelastically. Comparing the predicted axial stresses σ_b and σ_{ub} given in Tables 1 and 2 with the inelastic buckling stress given in Table 3 reveals that only the 6,000 g launch of the 0.19 in. case with unbonded propellant will probably survive. The 7,000 g launch of the 0.19 in. case with unbonded propellant is a border line case as is the same case under 6,000 g's with bonded propellant. All cases with thickness less than 0.19 in. will fail. This is shown graphically in Figure 2 where σ_b, σ_{ub}, σ_{cr}, $(\sigma_{cr})_{inelastic}$, and σ_{cy} are plotted as a function of h. The curves shown in Figure 2 are referred to here as the survivability curves. The survivability of a particular case to a specified acceleration is obtained by selecting the thickness along the abscissa and proceeding along the ordinate until either σ_b or σ_{ub}, depending upon the assumed bonding condition, is reached. The region the point lies in determines its survivability.

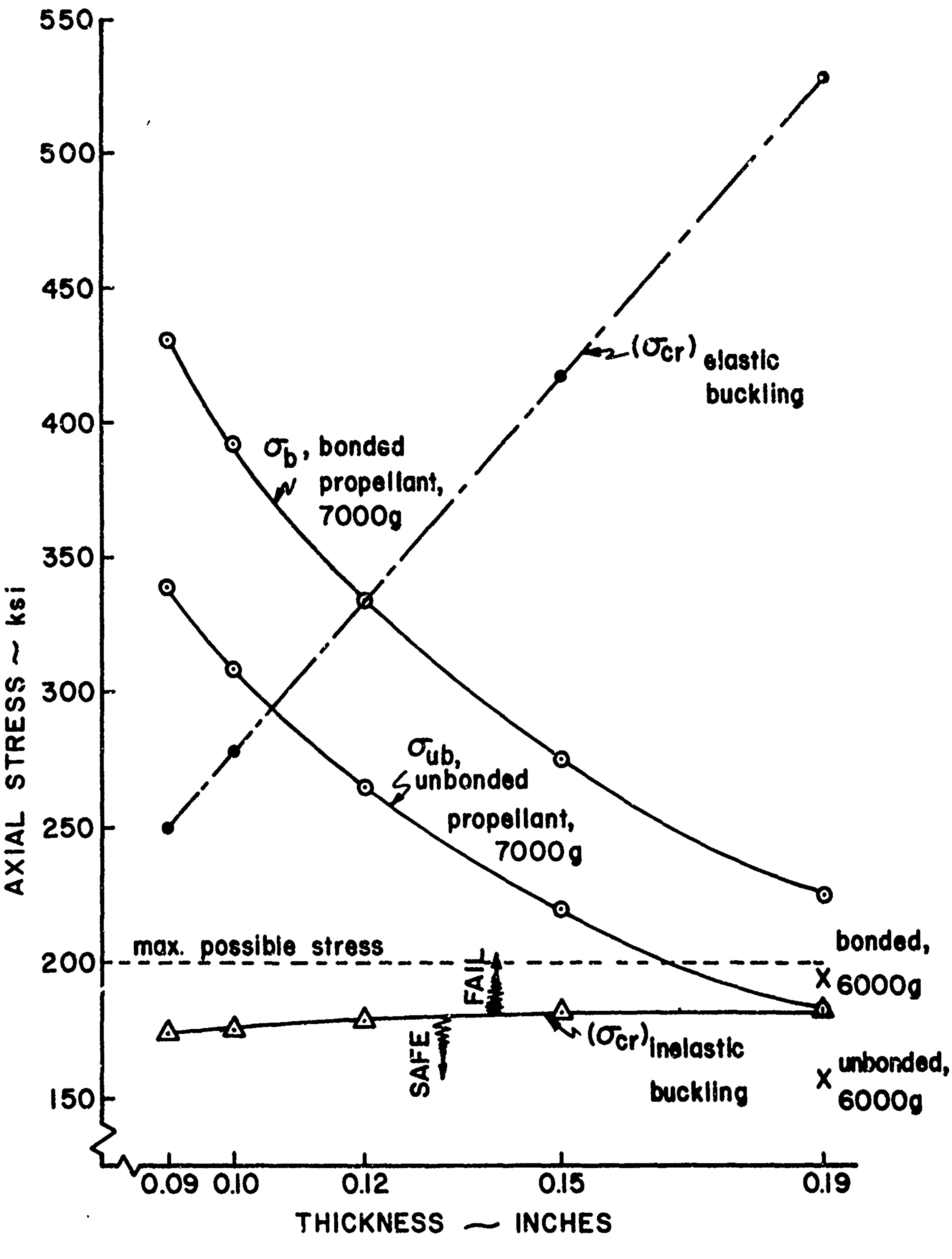

FIGURE 2. SURVIVABILITY CURVES

REFERENCES

1. Ball, Robert E., and Salinas, Dav.d, "Analysis of a Three Inch Gun Launched Finned Motor Case," Naval Postgraduate School, NPS-57Bp-72011A, January 1972.

2. Baker, E. H., et. al., "Shell Analysis Manual," NASA CR-912, April 1968.