[redacted] [redacted]

UNCLASSIFIED

[redacted]

[redacted]

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW DOWNGRADING OR DECLASSIFICATION STAMP	
CLASSIFICATION CHANGED TO: U Emelda Selph 5-6-97 PERSON CHANGING MARKING & DATE Carmela M Gallegos PERSON VERIFYING MARKING & DATE 5/20/97	AUTHORITY: W. C. Layne RECORD ID: 97SN1735 DATED: 5-6-97

50-56-51

AERODYNAMIC DESIGN OF TEST EQUIPMENT FOR MK 5 AND MK 15 WEAPON VULNERABILITY TEST AT REDWING

INVENTORIED 6-28-53

INVENTORIED

MAY 19 56

4161

INVENTORIED

MAY 1 1958

BY ORG. 27

INVENTORIED

MAY 22 '57

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW	
1st Review Date: 7-09-81 Authority: ☐ ADC ☒ ADD CCRP-RR Name: 2nd Review Date: 5-06-97 Authority: ADD Name: W Layne	Determination (Circle Numbers): 1. Classification Retained 2. Classification Changed to: U 3. Contains No DOE Classified Information 4. Coordinate With: 5. Contains UCAI? 6. Comments:

W. B. Pepper

ABSTRACT

The design of instrument cables and telemeter antennas to withstand blast winds in the close proximity of atomic explosions is considered for application to the Mk 5 and Mk 15 vulnerability tests at Redwing.

[redacted]

[redacted]

CENTRAL W A R March 30, 1958
CONTROL NO. 9

Case No. 409.07

57648

[redacted]

UNCLASSIFIED

[redacted]

[redacted] [redacted]

UNCLASSIFIED

DISTRIBUTION:

1/13A S. C. Hight, 5120
2/13A R. A. Ecer, 5200
3/13A G. E. Hansche, 5140
4/13A C. D. Broyles, 5111
5/13A D. B. Shuster, 5330
6/13A H. E. Hansen, 5226
7/13A R. K. Smeltzer, 7223-2
8-13/13A H. M. Willis, 7223

UNCLASSIFIED

[redacted]

[redacted] [redacted]

UNCLASSIFIED

SUMMARY

Instrument cables and telemeter antennas are needed for the Mk 5 and Mk 15 vulnerability tests at Redwing to conduct instrument response signals from the weapon cases, suspended freely in the blast wind from an atomic explosion, to the ground. The high overpressures of 40 to 500 psi impose extremely high aerodynamic loadings on any object exposed to the blast wind and necessitate special methods of conducting the instrument cable to the ground. The best method required use of a heavy steel tower downwind from the weapon. Suitable tower dimensions designed for 40, 70, 200, and 500 psi overpressures are presented.

The standard B-36 type spike antenna was found to be unsuitable for use in the tests because small angles of attack on the order of 1/4 degree would cause failure in side bending. An antenna consisting of a solid steel bar 16.8 inches long with a cross section one inch by three inches and rounded leading and trailing edges was designed to withstand up to 200 psi overpressure.

INTRODUCTION

Several Mk 5 and Mk 15 weapons will be subjected to extremely high overpressures from a 40-KT ground burst at Redwing to determine the vulnerability of the weapon cases and components when exposed to close proximity atomic bursts. Telemetering will be used to record accelerations[1] and component functioning. Cantilever antenna masts protruding from the weapon cases are desired for telemeter antennas. During the first few milliseconds, the telemetering information will be unusable because of the electromagnetic effects of the exploding atomic bomb. Therefore, an instrument cable is needed to transmit information from the weapon to the ground and on to the recording station. This memorandum considers the design of a telemetering antenna and towers to conduct the instrument cables to the ground.

PROBLEM

Instrument Cables

The test weapons will be suspended about five feet above the ground and will be free to respond to the blast wind. Some method is desired to conduct an instrument cable from the weapon to the ground with the least possible effect of the cable on the free weapon response. Two possible methods have been investigated. Appendix A discusses the design of a tower [illegible] cable leading to the ground.

[illegible] cable to the ground. Use of the cable to transmit signals for several seconds during the positive pressure phase would require considerable [illegible] the cable to allow for movement of the freely responding weapon. Rather than [illegible] the cable, the inclined cable was considered as being a more practical method.

[1] Reference [illegible] the proposed weapon tests and is an analysis of the aerodynamic parameters that produce forces and accelerations on the weapons.

UNCLASSIFIED

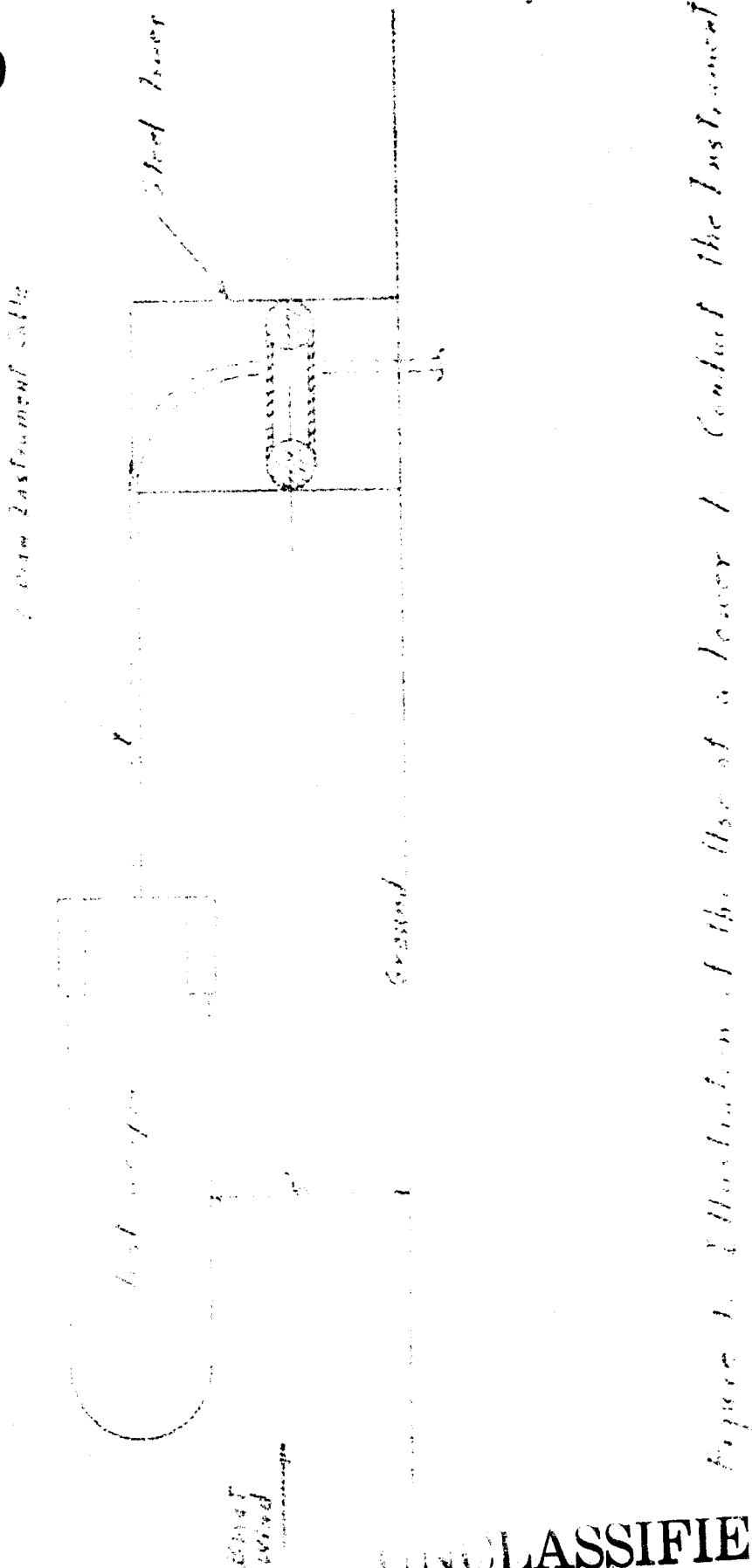
[redacted]

BY DATE SUBJECT [redacted] SHEET NO

CHKD BY DATE JOB NO

[redacted]

UNCLASSIFIED



UNCLASSIFIED

[redacted]

[redacted] [redacted]

Antenna

A telemetering antenna will radiate signals from the telemeter in the test weapon during the explosion. The antenna must be a cantilever spike protruding perpendicular to the side surface of the weapon case. Other types of antennas are believed to not operate properly since the weapon is near the ground. If possible, the standard B-36 type aircraft antenna should be used since such antennas are readily available. Appendix C is an analysis of the structural limitations of the standard antenna. An antenna design capable of withstanding 200 psi overpressure is also presented in Appendix C.

DISCUSSION

Even with a cable 40 feet long inclined at 8.1 degrees with respect to the weapon centerline and ground, the air loads due to cross-flow are of considerable magnitude (see Appendix B). The large additional forces imposed on the weapon by the cable are undesirable. The dynamic behavior of such a long cable might result in failure. Therefore, the tower design discussed in Appendix A is believed to be the best method to insure definite signal reception. Suitable tower dimensions for various overpressures are given in Table I.

TABLE I

Tower Dimensions Necessary to Withstand Given Overpressures
(Tower Height 8.4 Feet)

Overpressure (psi)	Diameter of solid cylinders (in.)	Center-to-center spacing of cylinders (in.)	Thickness of plates connecting cylinders (in.)
40	4.5	7.5	.31
70	4.5	13.5	.56
200	8.0	24.0	1.0
300	12.0	36.0	1.5

The standard aircraft antenna was found to be unsuitable for use in the tests because small angles of attack on the order of 1/4 degree would cause failure in side bending at 40 psi overpressure. A more rigid antenna design is discussed in Appendix C. The beam cross section is one inch by three inches with one-half-inch radius on the leading and trailing edges. The material from which the antennas are made should be high-strength steel with a yield stress of about 90,000 psi. This antenna will withstand overpressures up to 200 psi. The antenna has sufficient strength to withstand an angle of attack of 11.5 degrees.

[redacted]

CONCLUSIONS

Investigation of the aerodynamic loading on instrument cables and antennas for the Mk 5/Mk 15 weapon vulnerability tests at Redwing has led to the following conclusions:

1. Leading the instrument cables from the down-wind side of the test weapons to steel towers and then through the towers to the ground appears to be the most satisfactory method of leading the cable to the ground. (Suitable tower dimensions are given in Table I.)

2. The standard B-39 type antenna mast should not be used.

3. A new antenna, 19.8 inches long having a solid steel cross section one inch wide by three inches deep with 0.5-inch radius on the leading and trailing edges, will have sufficient strength to withstand 200 psi overpressures.

APPENDIX A

Design of Towers for Instrument Cables

The characteristic tower cross section that was selected is shown in Figure A-1. This cross section has been found to have sufficiently high inertia and moderate drag to withstand very high overpressures. Several towers discussed in Reference 2 had this cross section and successfully withstood atomic tests at Nevada. The dimensions of the cross section were standardized as functions of the cylinder diameter, D. Calculations similar to those of Reference 2 were made using the formulas listed below for values of D between 2 and 12 inches.

$$A = \frac{\pi D^2}{4}$$

$$I_{xx} = \frac{\pi D^4}{64}$$

$$I_{x'x'} = I_{xx} + Ay^2$$

$$y = 1.5D$$

$$I_p = \frac{1}{12} t h^3$$

$$t = 0.125\ D$$

$$I = 2\ (I_{x'x'} + I_p)$$

$$c = 2\ D$$

$$D_p = C_D\ q\ S$$

$$S = D\ \ell$$

$$w = \frac{D}{\ell}$$

$$M_s = \frac{w \ell^2}{2}$$

$$\sigma_s = \frac{M_s}{Dc}$$

where

D = diameter of sand cylinder (in)

A = cross-sectional area of one cylinder (in^2)

I_{xx} = moment of inertia of cylindrical cross section about xx axis (in^4) (see Fig. A-1)

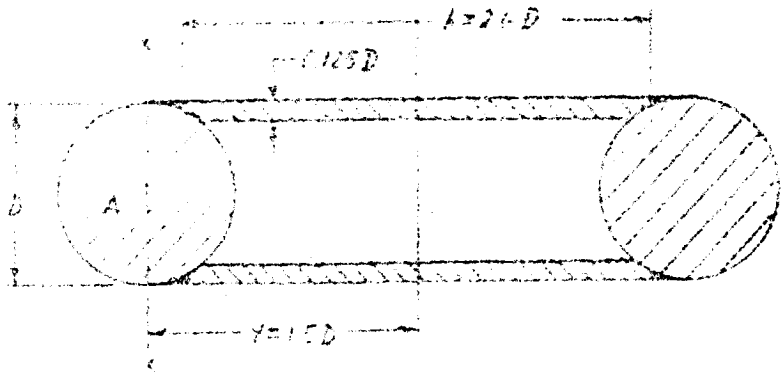


Figure- . Characteristic Tower Cross-Section.

ΔP	X	t_d (sec)
40	0.10 q_0	0.23
70	0.10 q_0	0.16
200	0.10 q_0	0.07
500	0.10 q_0	0.05

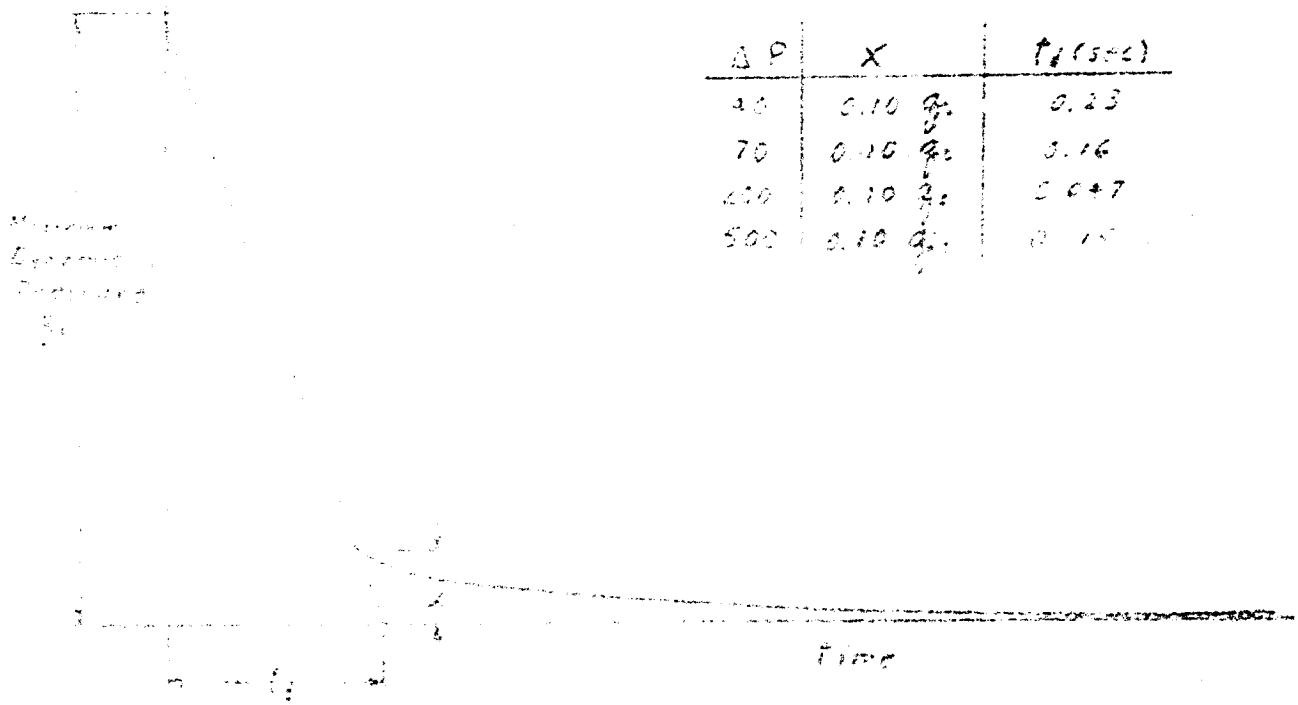


Figure- . Determination of Effective Loading Time (t_d).

$I_{x'x'}$ = moment of inertia of cylindrical cross section about x'x' axis (in^4) (see Fig. A-1)

y = distance between zx and x'x' axes (in)

I_p = moment of inertia of one plate joining the two cylinders about the x'x' axis (in^4)

t = plate thickness (in)

I = total moment of inertia of tower cross-sectional area about x'x' axis (in^4)

c = distance from x'x' axis to cylinder outer fiber (in)

D_F = drag force on tower (lb)

C_D = drag coefficient of tower

q = dynamic pressure of blast wave (lb/in^2)

S = tower frontal area (in^2)

ℓ = tower height (in)

w = drag load per unit tower length (lb/in)

M_B = maximum static bending moment at tower base (lb/in)

S_B = maximum static stress (lb/in^2)

Values of maximum dynamic pressure were used corresponding to overpressure levels of 40, 70, 200, and 500 psi. The values for dynamic pressure and Mach number were obtained from C. D. Broyles and are from the Los Alamos IBM problem "M" data. Drag coefficients of the tower were estimated and are presented in Table A-1.

TABLE A-1

Maximum Blast Wind Parameters

Overpressure (psi)	Dynamic pressure (psi)	Mach number	Tower drag coefficient
40	28	.85	1.5
70	63	1.07	2.0
200	330	1.52	1.5
500	1250	1.80	1.3

In order to evaluate the dynamic response of the towers to the blast loading, the natural period of vibration must be found using the formula for a cantilever beam.

$$T = \frac{1}{\sqrt{\frac{E\,I\,g}{w\,\ell^4}}}$$

[redacted] [redacted]

where

T = fundamental natural period of vibration (sec)

E = modulus of elasticity of metal from which tower is made (lb/in^2) (a value of 30×10^6 was used)

I = tower cross-sectional moment of inertia (in^4)

w = tower weight per unit length (lb/in)

g = acceleration of gravity (386 in/sec^2)

ℓ = tower height (in)

K = support constant = 0.56 for cantilever beam (first mode)

The blast loading period must also be known in order to predict the dynamic response of the towers.

The ratio t_d/T

where

t_d = duration of blast loading (sec)

T = fundamental natural period of tower vibration (sec)

was found for every tower and overpressure condition.

Values of t_d were determined by the time duration of an equivalent triangular pulse form as shown in Figure A-2. The complete positive phase duration was not used since the dynamic pressure decays very rapidly to an insignificant value. For a known value of t_d/T the ratio of maximum dynamic root moment to maximum static root moment can be found from Figure A-3. The data in Figure A-3 was taken from Reference 3.

Figure A-4 shows the maximum static and dynamic stresses at the tower root for the four selected overpressures and with various cylinder diameters. The selection of suitable tower dimensions can be made from Figure A-4 by selecting cylinder diameters equal to or larger than the values at the intersection of the dynamic stress curves (solid lines) with the 22,000 psi working stress line. For the 500 psi overpressure condition, a cylinder diameter of about 15 to 18 inches would be required in order to prevent the stress exceeding the working stress of 22,000 psi. Such large solid steel cylinders probably could not be readily obtained. It is therefore suggested to use a 12-inch diameter cylinder, designing on the yield stress instead of the working stress. (The tower drag coefficients given in Table A-1 are believed to be slightly conservative so that the 12-inch diameter cylinder should be safe for 500 psi.)

[redacted]

UNCLASSIFIED

[redacted]

UNCLASSIFIED

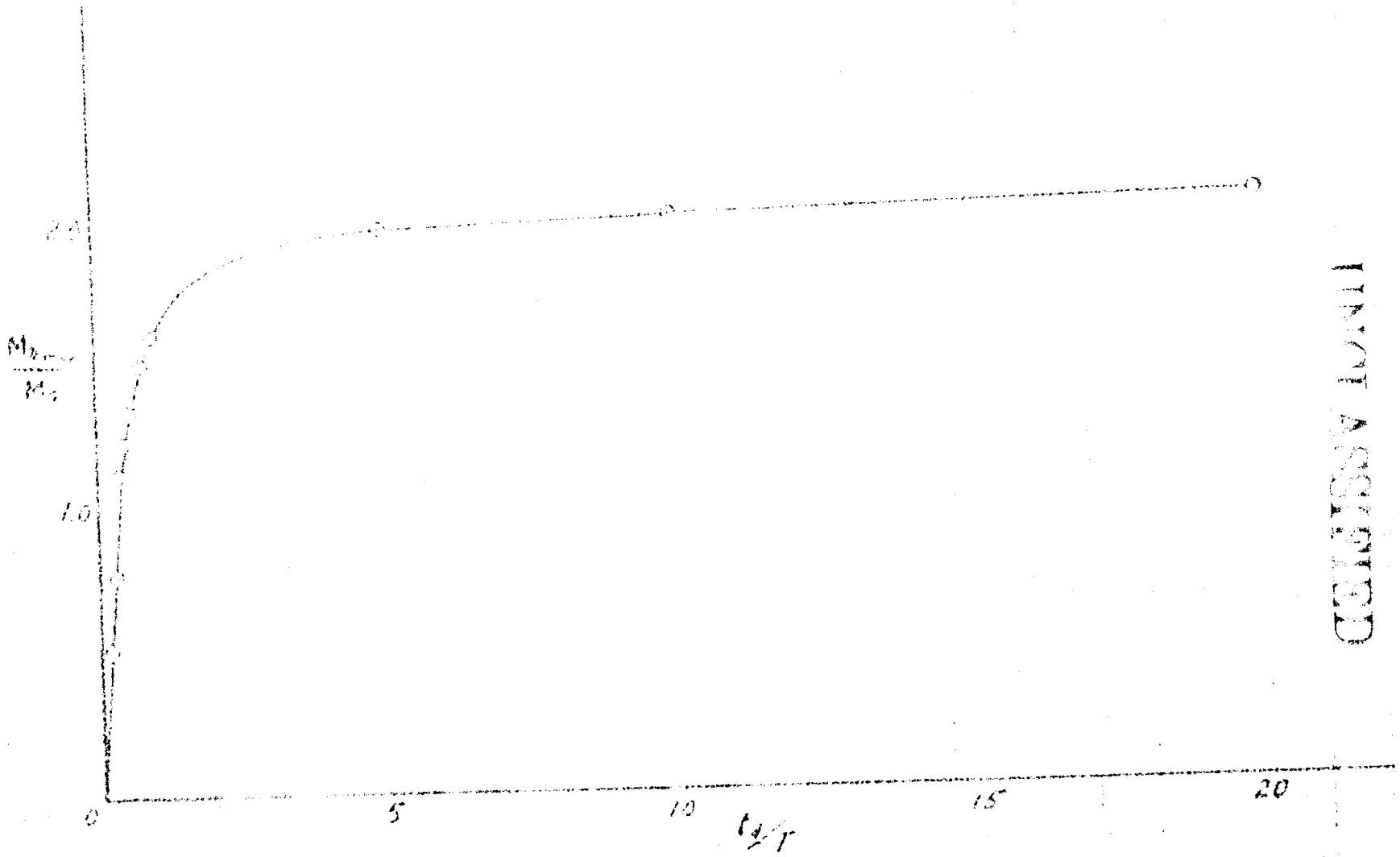


Figure: Variation in the Ratio of Maximum Dynamic Root Moment to Static Root Moment with The Ratio of Load Duration to Natural Vibrational Frequency for a Uniformly Loaded Cantilever Tower.

UNCLASSIFIED

[redacted]

[redacted]

SANDIA CORPORATION
ALBUQUERQUE, NEW MEXICO

REPORT NO. PAGE

UNCLASSIFIED

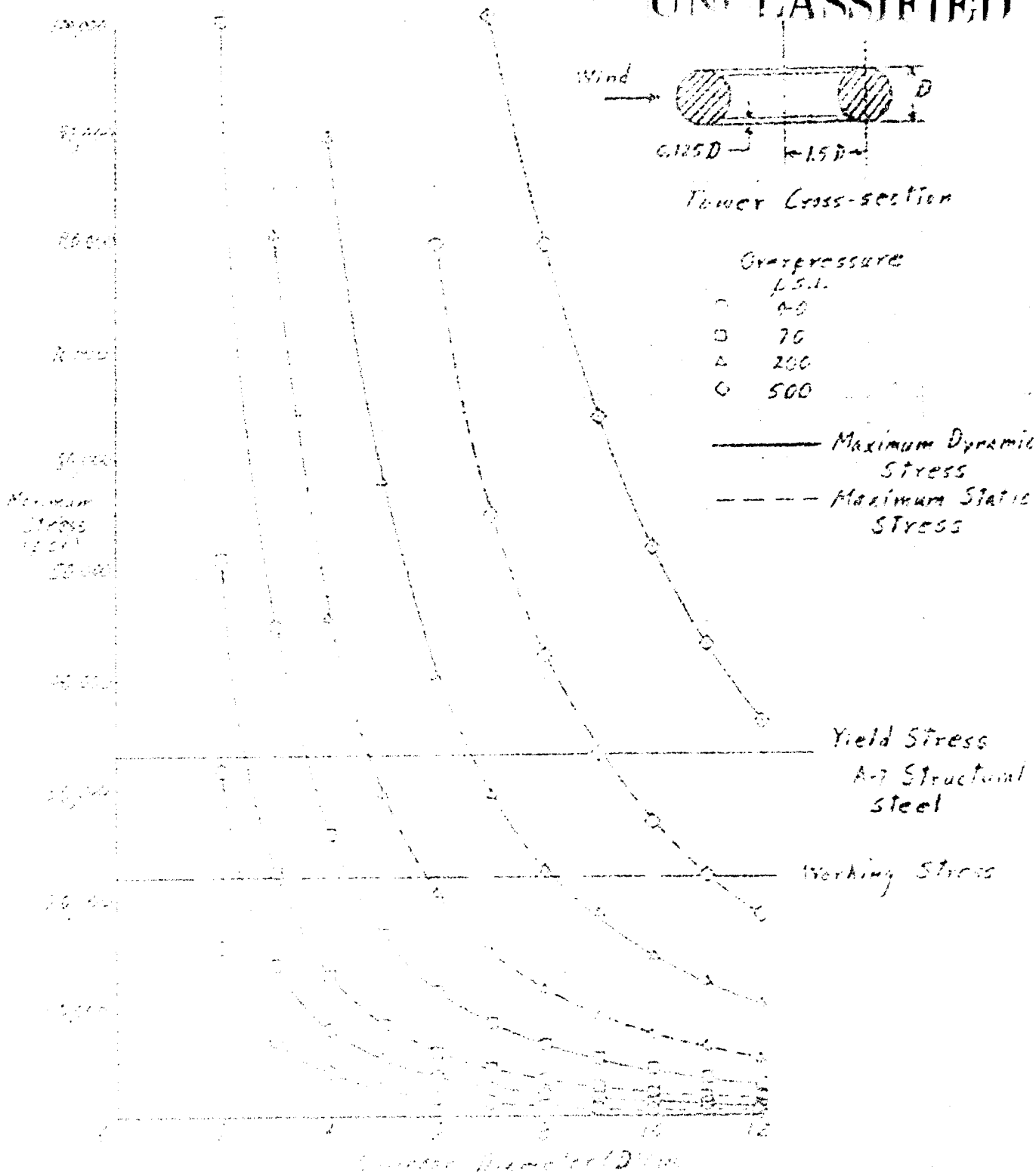


Figure . Variation of Maximum Static and Dynamic Stresses with Characteristic Dimension of a 64 Foot High Cantilever Tower Subjected to Various Overpressures from a 40KT Ground Atomic Burst.

UNCLASSIFIED

PREP. BY DATE

[redacted]

[redacted] [redacted]

APPENDIX B

Design of an Inclined Cable

A method of getting the cable down to the ground from the weapon is illustrated in Figure B-1. The cable is inclined to the blast wind an average angle of 3.1 degrees. The component of velocity perpendicular to the cable centerline will be

$$V_y = V_o \sin \theta \tag{B-1}$$

where

V_y = component of velocity perpendicular to cable centerline (ft/sec)

V_o = blast wind velocity (ft/sec)

θ = angle between ground and cable centerline (deg)

The dynamic pressure is

$$q_y = \frac{1}{2} \rho V_y^2 = \frac{1}{2} \rho V_o^2 \sin^2 \theta = q_o \sin^2 \theta \tag{B-2}$$

where

q_y = dynamic pressure due to V_y (lb/in)

ρ = air density (slugs/ft^3)

q_o = dynamic pressure of blast wind (lb/ft^2)

Considering the test that will be conducted at 500 psi overpressure, the dynamic pressure from Table A-1 is

$$q_o = 1210 \text{ psi}$$

Using Equation (B-2),

$$q_y = q_o \sin^2 \theta = 1200 \sin^2 3.1$$

$$q_y = 30 \text{ lb/in}^2$$

The drag load in the (y) direction will be

$$D_y = C_D q_y S_y \tag{B-3}$$

where

D_y = drag force in y direction (lb)

C_D = drag coefficient

S_y = projected area of cable (in^2)

 [redacted]

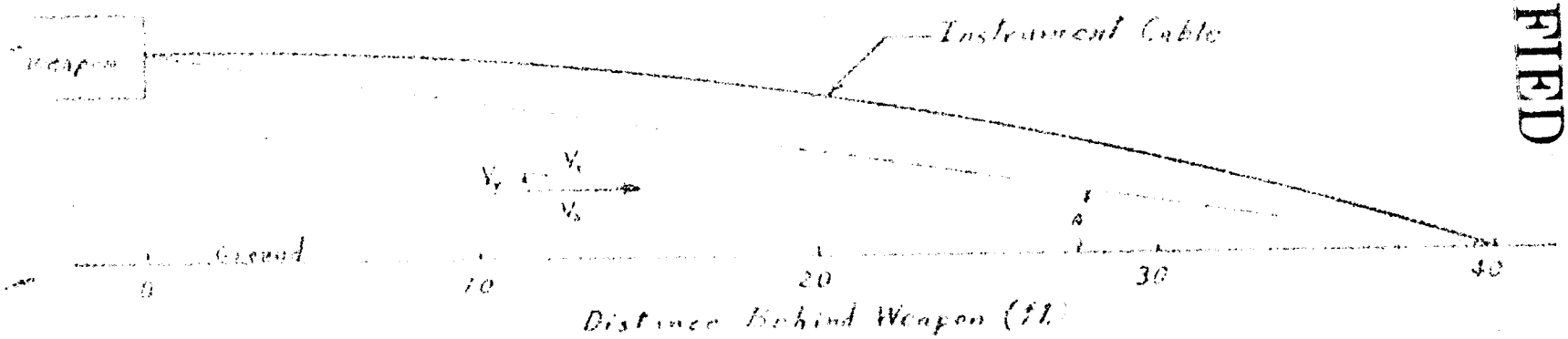


Figure-1. Inclined Instrument Cable from Weapon to Ground.

Assuming a 2-inch cable,

$$S_f = 2\ (40)\ (12) = 960\ in^2$$

A drag coefficient of 1.2 for a cylinder will be used since V_y is subsonic. Substituting in Equation (B-3)

$$D_y = 1.2\ (30)\ (960) = 34,500\ lb$$

As a rough approximation the cable will be assumed to be loaded uniformly by the drag load (D_y) and to deflect so that the centerline forms a parabola. The tension load at the end of the cable can then be calculated by the method given on page 194 of Reference 4.

$$P_a = \frac{wb}{2}\sqrt{\frac{b^2}{16h^2} + 1} \qquad \text{(B-4)}$$

where

P_a = maximum tension at end of cable (lb)

w = unit loading (lb/ft)

b = distance between end supports (ft)

h = distance from cable centerline to axis passing through both cable and supports (ft)

A value of (h) can be determined by assuming the cable will trail back from the weapon in the direction of the blast wind, that is, parallel to the weapon axis. Using the formula from Reference 4,

$$\tan \theta_A = \frac{4h}{b} \qquad \text{(B-5)}$$

where

θ_A = angle of cable centerline at ends (deg)

$$h = \frac{b \tan \theta_A}{4} = \frac{40 \tan 9.1}{4} = 1.6\ ft$$

The maximum tension at the cable ends is found using Equation (B-4).

$$P_a = \frac{34,500}{2}\sqrt{\frac{(40)^2}{16(1.6)^2} + 1}$$

$$= 17,250\ (5.81) = 100,000\ lb.$$

The cable size required to withstand this load will be about 1-3/8 inches in diameter. The breaking strength of a 1-3/8-inch cable is 157,000 lb. Considering the assumed instrument cable outside diameter of 2 inches, there remains 3/16 inch on a radius for instrument wires and outer shield. An additional force will be imposed on the weapon because of the skin friction drag of the instrument cable.

$$D_x = C_{D_f} q_x S_s \tag{B-6}$$

where

D_x = friction drag force in x direction (lb)

C_{D_f} = skin friction drag coefficient assumed to be 0.003

q_x = dynamic pressure in x direction (lb/in^2)

S_s = instrument cable surface area (in^2)

The dynamic pressure in the x direction is

$$q_x = q_0 \cos^2 \theta = 1170 \text{ lb/in}^2$$

The friction drag is

$$D_x = .003\ (1170)\ (3010) = 10,600 \text{ lb.}$$

The total force acting on the weapon as a result of the loads on the 2-inch cable is the sum of equations (B-1) and (B-6).

$$F = F_a + D_x = 119,600 \text{ lb.}$$

If more space is desired in the cable for instrument wires the diameter could be increased from 2 inches to 2.5 inches. Considering a 2.5-inch diameter instrument cable,

$$D_f = 1.2\ (30)\ (1200) = 43,200 \text{ lb}$$

$$F_a = \frac{43,200}{2}\ (2.5) = 135,000 \text{ lb}$$

$$D_x = .003\ (1170)\ (8770) = 13,200 \text{ lb}$$

$$F = 148,200 \text{ lb}$$

APPENDIX C

Design of Antenna

B-36 Type Antenna. -- The standard B-36 type aircraft antenna shown in Figure C-1a was first considered for installation on the test weapon cases, since such antennas were readily available. However, the structural integrity of such a long thin surface subjected to 10, 70, and 200 psi overpressures was not known. The antenna will first be analyzed for the lowest overpressure condition of 40 psi. The front view of the antenna shown in Figure C-1a was analyzed for chordwise bending at zero degrees angle of attack. Since the maximum Mach number for 40 psi overpressure is 0.85, the drag coefficient was assumed to be 0.5 based on the frontal area of the antenna. Nine incremental lengths were used to obtain the static root bending moment about the xx axis,

$$M_{s_x} = 366 \text{ in/lb.}$$

Assuming a dynamic amplification factor of 2 results in a dynamic root bending moment of

$$M_{D_x} = 732 \text{ in/lb}$$

The root section moment of inertia about the xx axis is

$$I_{xx} = .0217 \text{ in}^4$$

The maximum dynamic stress is

$$S_{D_x} = \frac{M_{D_x} c}{I_{xx}} = \frac{732\left(\frac{366}{2}\right)}{.0217}$$

$$S_{D_x} = 4480 \text{ psi}$$

The antenna is made of cast aluminum which has a tensile strength of 30,000 psi. Therefore, [illegible] to drag forces will not cause failure at 40 psi overpressure. However, a small angle of attack caused by misalignment of the antenna on the weapon or rotation of the weapon with respect to the blast wind may produce high lift forces. The lift curve slope may be approximated by

$$C_{L_\alpha} = \frac{2\pi AR}{(AR + 2)\,57.3}$$

where

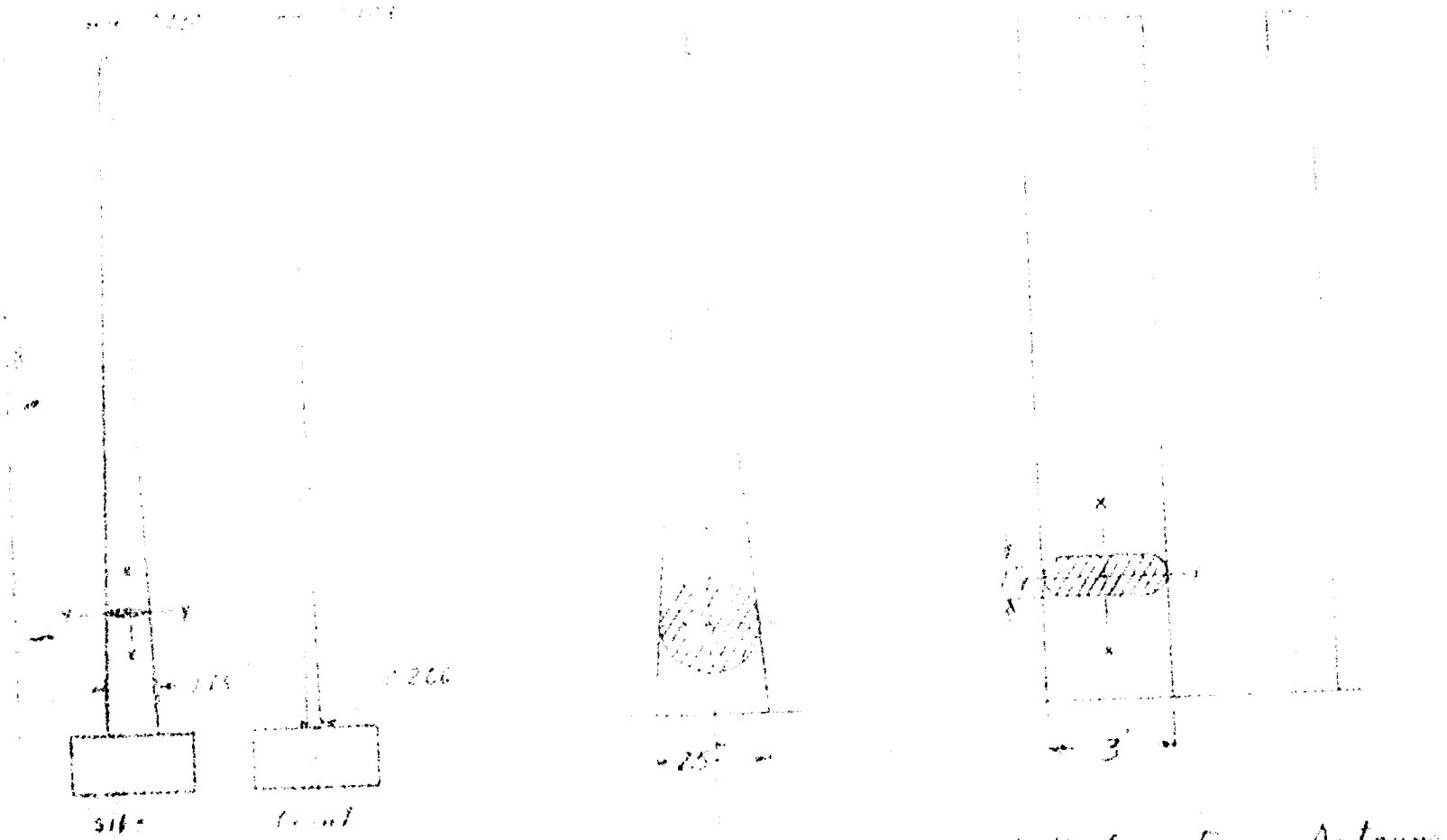
C_{L_α} = lift curve slope (per degree)

$AR = \frac{b^2}{S}$ = aspect ratio

b = wing length (in)

S = wing area (in^2)

[redacted]



(a) Standard [illegible] Antenna (b) Spike Antenna. ( ) Uniform Beam Antenna

Figure - Antenna Configurations Considered for Weapons.

[redacted]

[redacted] [redacted]

The aspect ratio of the B-58 antenna is

$$AR = \frac{(19.8)^2}{12.9} = 22$$

The L_α curve slope is

$$C_{L_\alpha} = \frac{2\pi(22)}{(22+2)\,57.3} = 0.010/\text{deg}$$

The lift force is

$$L = C_{L_\alpha}\,\alpha\,q\,S$$

where:

L = lift force (lb)

α = angle of attack (deg)

q = dynamic pressure (psi)

For the 40 psi overpressure condition, the dynamic pressure is 28 psi from Table A-1 and the lift force is

$$L = .10\,\alpha(28)\,(12.9) = 35.1\alpha$$

The lift force acts through the wing center of pressure which is approximately 7 inches from the wing root. The resulting static root moment is

$$M_{s_y} = L\,z$$

where:

M_{s_y} = static root moment about yy axis (lb-in)

z = distance from center of pressure to root (7 in)

Thus

$$M_{s_y} = 35.1\alpha\,(7) = 246\,\alpha$$

The maximum dynamic root moment is found by assuming a dynamic amplification factor of 2.0:

$$M_{D_y} = 2M_{s_y} = 492\,\alpha$$

The root stress is

$$\sigma_{D_y} = \frac{M_{D_y}\left(\frac{t}{2}\right)}{I_{yy}}$$

[redacted]

[redacted] [redacted]

UNCLASSIFIED

where

S_{D_y} = maximum dynamic stress due to M_{D_y} (psi)

t = airfoil thickness (in)

I_{yy} = wing root section moment of inertia about yy axis (in^4)

Therefore,

$$S_{D_y} = \frac{504\,\alpha\left(\frac{t}{2}\right)}{I_{yy}}$$

The maximum angle of attack permissible can now be found by assuming a yield stress of 20,000 psi

$$\alpha = \frac{S_{D_y}\,I_{yy}}{504\left(\frac{t}{2}\right)} = \frac{20,000\,(.000783)}{504\left(\frac{.255}{2}\right)}$$

$$\alpha = .237 \text{ deg}$$

Maintaining an angle of attack of the antenna less than 0.237 degree will be impractical for the planned tests. Therefore, the B-35 type antenna should not be used.

Antenna for 200 psi Overpressure. -- A uniformly tapered solid steel cone shown in Figure C-1b was first tried for the antenna. With a 2.5-inch root diameter the maximum dynamic stress at the root was calculated to be 80,000 psi if the antenna is subjected to 200 psi overpressure. High carbon steel could be used to withstand this stress. However, the stress at 3/4 of the antenna length from the root would be 757,000 psi. A nonuniformly tapered beam would therefore have to be used. Such a beam would be difficult to machine. Therefore, the antenna cross section shown in Figure C-1c was selected because of its high sectional moment of inertia and ease of fabrication. Using a cross-section width of one inch and length of three inches results in a maximum dynamic stress of 65,200 psi. The use of a suitable high-strength steel will withstand this stress.

To prevent excessive side lift forces the antenna should be positioned with the narrow width facing the blast wind, that is, an angle of attack of zero. The permissible deviation from zero angle of attack will be calculated as was carried out for the B-35 type antenna. The maximum static root bending moment for a uniformly loaded beam is

$$M = \frac{wl^2}{2}$$

where

w = loading per unit length (lb/in)

l = beam length (in)

The dead loading is

$$w = \frac{l}{l}$$

[redacted]

UNCLASSIFIED

[redacted] [redacted]

UNCLASSIFIED

where

L = lift force on beam (lb)

The lift force can be found by

$$L = C_{L_\alpha} \alpha q S$$

where

C_{L_α} = lift curve slope (1 deg)

α = angle of attack (deg)

q = dynamic pressure (330 psi for the 200 psi overpressure condition)

S = wing area ($3 \times 16.8 = 50.4$ in^2)

The lift curve slope is

$$C_{L_\alpha} = \frac{2\pi AR}{(AR + 2)\, 57.3}$$

where the aspect ratio is

$$AR = \frac{b}{w} = \frac{16.8}{3} = 5.6$$

Then,

$$C_{L_\alpha} = \frac{2\pi(5.6)}{(5.6 + 2)\, 57.3} = .081/\text{deg}$$

The lift force is then

$$L = .081\,\alpha\, 330(50.4) = 1350\,\alpha$$

The unit loading is

$$w = \frac{L}{l} = \frac{1350\,\alpha}{16.8} = 80.3\,\alpha$$

The static moment about the yy axis resulting from the lift force is

$$M_{D_y} = \frac{w\, l^2}{2} = \frac{80.3\,\alpha\,(16.8)^2}{2} = 11{,}300\,\alpha$$

[illegible]

$$M_{D_y} = M_\alpha = 23{,}000\,\alpha \text{ lb-in}$$

The maximum [illegible] is

$$\delta_{D_y} = \frac{M_{D_y}\left(\frac{l}{2}\right)}{I_{yy}}$$

[redacted]

UNCLASSIFIED

[redacted] [redacted]

The section moment of inertia is

$$I_{yy} = \frac{\pi D^4}{64} + \frac{S t^3}{12} = \frac{\pi (1)^4}{64} + \frac{2(1)^3}{12}$$

$$I_{yy} = .216$$

The antenna will be assumed to be made of steel having a yield stress of 60,000 psi

$$M_{D_y} = \frac{S_{D_y} I_{yy}}{r/2} = \frac{60,000\,(.216)}{.5} = 260,000$$

Equating,

$$22,000\,\alpha = 260,000$$

$$\alpha = 11.8^{\circ}$$

Aligning the antenna at zero angle of attack is not critical for this design.

[redacted]

[redacted] [redacted]

REFERENCES

1. W. B. Pepper, 5141, "Response of MK 5 and MK 15 Weapons to Atomic Blasts at Redwing", Sandia Corporation, T M 2[illegible]-56-51.

2. W. B. Pepper, "Design of Instrument Towers for Nevada Test Site", Ref. Sym: 5141-(5[illegible])

3. W. J. Franey, "A Study of Blast Loading Transmitted to Building Frames", University of Illinois Thesis.

4. F. L. Doran, Engineering Mechanics.

[redacted]