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6 DAMAGE TO AIRCRAFT BY BLAST.

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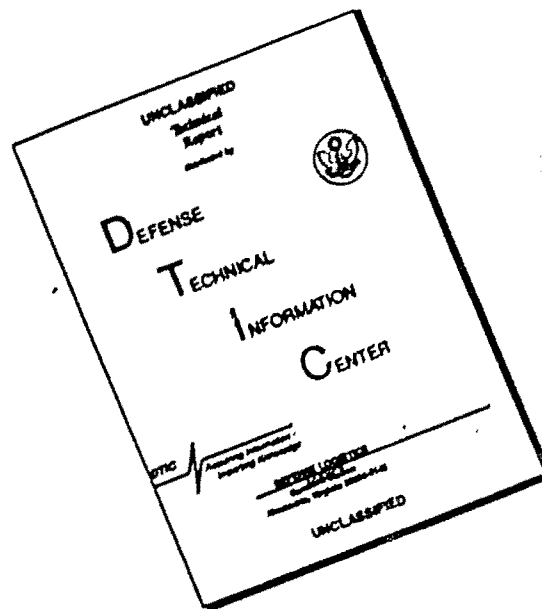
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NPG REPORT NO. 1058

U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

①

First Partial Report
on
Damage to Aircraft by Blast



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Damage to Aircraft by Blast

MEASUREMENT OF BLAST PARAMETERS

1. In investigating the effect of blast on structural components of aircraft, the components were subjected to blast waves from bare charges of TNT, and the critical blast parameters were measured by an array of instrumentation located near the components and at the same radius from the charge. This report discusses those phases of the instrumentation and the measurement techniques which are pertinent in evaluating results of the tests.

2. The instrumentation was designed to provide information on the following significant blast parameters:

- a. A time history of free overpressure.
- b. A time history of the reflected overpressure.
- c. Free air peak overpressures using the velocity method.

From the above, additional parameters, such as the duration of the positive phase and the impulse can be determined. Cathode-ray recording oscilloscopes have been provided for recording all the above parameters. In addition, a high speed camera has been used in some tests to record the movement of the shock front by the "broken wire" method. Two Buck interferometer gages were obtained to supplement the time history recording. However, the Buck gages were not in operating condition when received and subsequent work was not successful in attaining satisfactory operation. In an attempt to get some information, one of the gages was set-up on a recoiling platform and operated on detonation 27. The gage was damaged as a result of the blast, the monochromatic filter was detached and the springs holding the cover plate were stretched and released the cover. Further work with these gages was discontinued.

3. The array of gages for oscillographic instrumentation consisted of two double-faced, edge-on, piezo-electric gages for measuring free overpressure versus time and two single-faced, face-on, piezo-electric gages for measuring reflected pressure versus time. Eight velocity gages were mounted in two horizontal rows at the start of the test. However, as the work progressed the gages were placed on more substantial stands, and were arranged in three dimensional arrays in order to record the directional effects of the blast. Details of the orientation of the gages are given in Appendix (C), Figures 8, 9, 10, and 11.

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4. Two complete instrument trailers were fitted out with Cathode-ray recording instruments and tested in the field by detonating small charges. Appendix (C), Figures 12 and 13 are block diagrams of the instrumentation system. The trailers were protected from direct action of the blast by an earth bunker at the test site.

5. The Rankine-Hugoniot equations were used to compute peak pressure from the blast velocity data: $\frac{P_s}{P_o} = \frac{2\gamma}{\gamma+1} \left(\frac{U^2}{C^2} - 1 \right)$

where P_s = Shock wave overpressure

P_o = Atmospheric pressure

γ = Ratio of specific heats for air = 1.40

U = Shock wave velocity

C = Velocity of sound

In these equations, the governing quantity is the ratio between shock velocity and sound velocity. If different sets of gages are used to measure these two velocities, it is essential that the space intervals between gages be known with extreme precision.

In order to avoid the necessity for precise measurements of gage positions, the sound velocity was measured with the same sets of gages as were used for shock velocity. The procedure for accomplishing this involved mounting a small charge as a sound source, in line with the charge and the gages, and igniting this "cap" approximately 200 milliseconds before detonating the charge. With this method, not only are any inaccuracies in the measurement of gages intervals cancelled, but also errors in the accuracy of the time base are cancelled. It is recognized that this method provides only a partial compensation for wind velocity, since it is based on the approximation that:

$$\frac{U + W}{C + W} = \frac{U}{C}$$

U = Shock wave velocity

C = Velocity of sound

W = Wind velocity component parallel to direction of blast wave propagation.

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However, the above approximation introduces errors of such small magnitude that they were considered negligible under wind conditions prevalent during the tests reported herein. For example, a value of W of 30 fps would produce an error of only 3 per cent in a 10 psi

shock pressure determination. For convenience, a curve of $\frac{P_s}{P_o}$ versus

$\frac{U}{C}$ was drawn and is included as Figure 1, Appendix (A). The upper curve in Figure 1 is the shock wave pressure based on a nominal atmospheric pressure of 14.7 psi.

6. The results of measurements of blast parameters are contained in Appendix (B). An examination of the preliminary data shows that when pressures were computed from velocity gages, under the assumption that the blast front progressed in a direction parallel to a line between the charge and the gages, (i.e., true spherical wave), the upper and lower rows of velocity gages, (for heights, see Appendix (C), Figures 8, 9, 10, and 11), yielded peak pressure values which differed by an amount sufficient to imply a definite causative condition, although the decay of pressure, as recorded by successive intervals in each row, appeared reasonable. Figure 5, Appendix (C), shows these results graphically. In general, the upper row of gages indicated the higher pressure, and there is some possibility that such a pressure differential actually existed. However, no such discrepancy existed between the upper and lower edge-on gages (see Figure 4, Appendix (B)) and in several cases the condition was reversed, i.e., the lower velocity gages indicated the higher pressures. On the hypothesis that the above results might be due to propagation of the wave in a direction slightly different from that of spherical propagation, a formula was derived whereby one pressure value is derived from the first two gages in both rows, and is independent of the direction of propagation of the wave. The pressures derived by this method are considered to be very close to the true pressures and to be the most reliable values of pressure obtained in the tests. These values determine a well-defined curve (Figure 3, Appendix (B)) when plotted against reduced distance. The derivation of the formula is included in paragraph 9.

7. The method of stacking the TNT blocks to form the charge is shown in Appendix (C), Figure 15. All of the sketches on this diagram show the charges as they would appear to an observer standing 45° to the right of the line between the charges and the gages or aircraft structures. Appendix (C), Table V, contains further details on the charges. The ideal charge shape for the purpose of this test would have been spherical, but the large physical size of the individual

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blocks prohibited a spherical arrangement. Consequently, on detonations 12, 13 and 14, the arrangement was in the form of a low square (flat distribution). On the remaining detonations, an attempt was made to arrange the blocks so as to approximate a vertical cylinder, within the limits imposed by the number of blocks required. There is no doubt that the stacking arrangement produces directional effects. In detonations 12, 13 and 14 the charge distribution was low and symmetrical about the vertical axis. The results (see Figures 3-6 at $Z = 8.8-9.3$) are about 25% below a curve through the other points. It is likely that the more subtle stacking variations, which would exist even in those detonations ostensibly identical, greatly contribute to the scatter of observed pressures. In the next phase of the test, every attempt will be made to obtain uniform charge arrangements.

8. In Figure 7, Appendix (B), is shown the correlation between the pressures measured by the edge-on gages and those derived from the velocity method. It can be seen that the edge-on gage yielded slightly higher values in low pressures and their apparent sensitivity is reduced in the higher pressures. The latter is to be expected from the effects of mass flow.

9. Derivation of Formula used in Computing Derived Pressures.

The gage stand used for the first 26 detonations was particularly sensitive to the angle of arrival of the blast wave. From Figure 2, Appendix (A), it can be seen that if a blast wave arrives at an angle ϕ , with the centerline of the gage array, the time interval measured by gages 1 and 2 will be considerably shorter than the interval measured by gages 5 and 6.

The following is a derivation of a formula for computing the velocity ratio $\frac{U}{C}$ and thus the shock wave overpressure for the case in

which the pressure front of velocity U produced by the charge and the pressure front of velocity C produced by the cap are incident on the gage stand from different directions. The derivation utilizes the fact that, from the two pairs of gages, two linearly independent equations (1A and 1B below) in two unknowns may be obtained. The two unknowns, velocity and angle of arrival, can therefore be solved independently.

In Figure 2, Appendix (A), ϕ is the angle between the center line of the gage stand and the projection on a horizontal plane of the normal to the blast front. α is the angle of orientation of the gage pairs (#1 to #2 and #5 to #6) with respect to the center line. h , in feet,

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is measured in a direction parallel to, and a , in feet, is measured in a direction perpendicular to the center line. h and a form the two legs of a right triangle whose hypotenuse terminates in a gage at each end. V is the average velocity over each gage pair, assumed the same for each gage pair. τ_{12} is the time interval as measured by the first gage pair of the upper set (gages #1 and #2). τ_{56} is the time interval as measured by first pair of the lower set (gages #5 and #6).

Although the gage pairs were displaced above and below the center line for most detonations, since both gages of each pair are at the same height, the time intervals are measures of the horizontal component of velocity. The error introduced by neglecting the vertical component of velocity is, in this case, small compared with the errors resulting from the horizontal angle ϕ . The three dimensional derivation eliminates this error.

From Figure 2, in the time interval τ_{12} (time $T_2 - t_1$), the blast front travels a distance $V\tau_{12}$. Since side $A =$ side $B = \sqrt{h^2 + a^2}$,

$$1a) \quad V\tau_{12} = \sqrt{h^2 + a^2} \cos(\alpha + \phi) \text{ and}$$

$$1b) \quad V\tau_{56} = \sqrt{h^2 + a^2} \cos(\alpha - \phi).$$

Expanding,

$$V\tau_{12} = \sqrt{h^2 + a^2} \cos \alpha \cos \phi - \sqrt{h^2 + a^2} \sin \alpha \sin \phi$$

$$V\tau_{56} = \sqrt{h^2 + a^2} \cos \alpha \cos \phi + \sqrt{h^2 + a^2} \sin \alpha \sin \phi.$$

$$\text{since } h = \sqrt{h^2 + a^2} \cos \alpha \text{ and } a = \sqrt{h^2 + a^2} \sin \alpha$$

$$2a) \quad V\tau_{12} = h \cos \phi - a \sin \phi$$

$$2b) \quad V\tau_{56} = h \cos \phi + a \sin \phi.$$

Adding 2a and 2b and collecting terms,

$$3a) \quad \cos \phi = \frac{V}{h} \left(\frac{\tau_{12} + \tau_{56}}{2} \right).$$

Subtracting 2a from 2b and collecting terms,

$$3b) \quad \sin \phi = \frac{V}{a} \left(\frac{\tau_{56} - \tau_{12}}{2} \right).$$

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Squaring 3a and 3b and adding,

$$\left[\frac{V}{h} \left(\frac{\tau_{12} + \tau_{56}}{2} \right) \right]^2 + \left[\frac{V}{a} \left(\frac{\tau_{56} - \tau_{12}}{2} \right) \right]^2 = 1$$

since $\cos^2 \theta + \sin^2 \theta = 1$ for any angle θ .

Solving the above for V,

$$4) \quad V = \frac{1}{\sqrt{\left[\frac{1}{h} \left(\frac{\tau_{12} + \tau_{56}}{2} \right) \right]^2 + \left[\frac{1}{a} \left(\frac{\tau_{56} - \tau_{12}}{2} \right) \right]^2}}$$

A convenient form of equation 4 is

$$5) \quad V = \frac{h}{\sqrt{\left(\frac{\tau_{12} + \tau_{56}}{2} \right)^2 + \frac{h^2}{a^2} \left(\frac{\tau_{56} - \tau_{12}}{2} \right)^2}}$$

If $\tau_{56} - \tau_{12}$ is very small, 5 becomes h divided by the average of the intervals τ_{12} and τ_{56} . $\tau_{56} - \tau_{12}$ is proportional to the deviation from the case $\tau_{12} = \tau_{56}$ or $\phi = 0$.

From 3a and 3b,

$$6) \quad \phi = \tan^{-1} \left[\frac{h}{a} \left(\frac{\tau_{56} - \tau_{12}}{\tau_{56} + \tau_{12}} \right) \right]$$

Let U be the velocity of the blast front with intervals

T_{12} and T_{56}

Let C be the velocity of the cap front (used as the velocity of sound) with intervals t_{12} and t_{56} .

From equation 5,

$$7) \quad \left(\frac{U}{C} \right)^2 = \frac{\left[\frac{t_{56} + t_{12}}{2} \right]^2 + \left[\frac{h}{a} \left(\frac{t_{56} - t_{12}}{2} \right) \right]^2}{\left[\frac{T_{56} + T_{12}}{2} \right]^2 + \left[\frac{h}{a} \left(\frac{T_{56} - T_{12}}{2} \right) \right]^2}$$

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This final result is employed in the Rankine-Hugoniot equation

$$c) \quad \frac{P_s}{P_0} = \frac{2\gamma}{\gamma+1} \left[\left(\frac{U}{C} \right)^2 - 1 \right]$$

where P_s is the blast overpressure, P_0 is the atmospheric pressure, and γ is the ratio of specific heats for air.

Since $t_{56} - t_{12}$ is relatively small in comparison with $t_{56} + t_{12}$, reasonable errors in h and a cause very little error in the derived pressure P_s .

The above derivation provides only a two dimensional correction for angle of arrival. The three dimensional case has been worked out. Two new gage stands have been constructed whose design (see Figure 11) was based on this latter derivation. They have been used on all detonations subsequent to number 26. The three dimensional derivation, together with other necessary considerations, is to be in a later report. The resulting equation which was used in computation of derived pressures for detonations 27 to 31 is:

$$9) \quad \left(\frac{U}{C} \right)^2 = \frac{t_{13}^2 + \frac{1}{a_2^2} [h_3 t_{12} - h_2 t_{13}]^2 + \frac{1}{a_4^2} [h_3 t_{14} - h_4 t_{13}]^2}{T_{13}^2 + \frac{1}{a_2^2} [h_3 T_{12} - h_2 T_{13}]^2 + \frac{1}{a_4^2} [h_3 T_{14} - h_4 T_{13}]^2}$$

Where: U is Shock wave velocity

C is Sound velocity

h_3 is longitudinal distance from gage 1 to gage 3 (the baseline)

h_2 is longitudinal distance from gage 1 to gage 2

h_4 is longitudinal distance from gage 1 to gage 4

a_2 is lateral distance from baseline to gage 2

a_4 is lateral distance from baseline to gage 4

t_{12} , t_{13} , & t_{14} are the time intervals from the first gage to the Nos. 2, 3, and 4 gages, respectively, obtained from the sound detonation.

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T_{12} , T_{13} , & T_{14} are the corresponding time intervals obtained from the shock wave.

In either the numerator or the denominator, the first term of equation 9 may be called the baseline term, the second term called the horizontal deviation term, and the last the vertical deviation term.

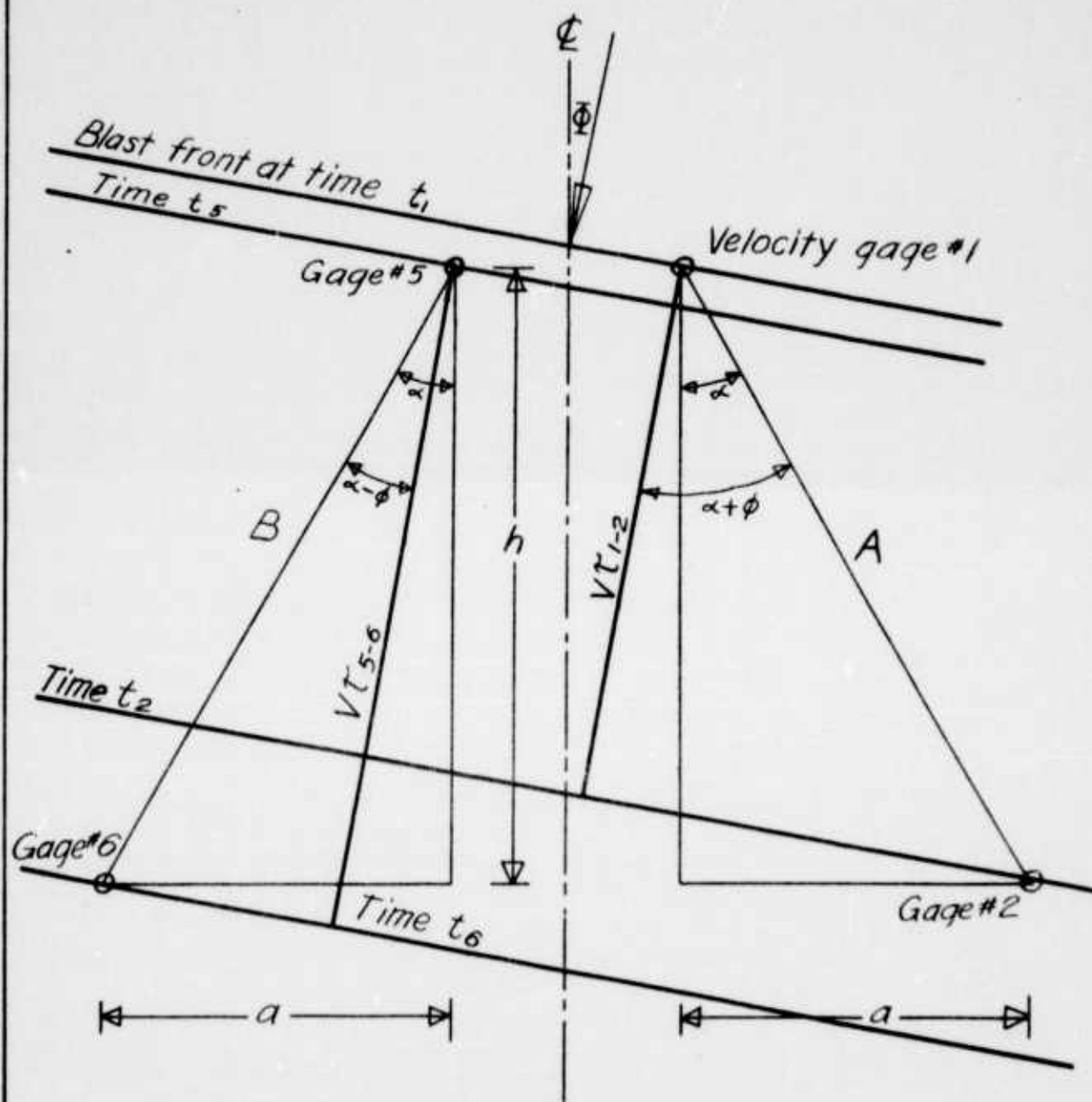
The similarity between equations 7 and 9 can be seen if the average term, $\frac{T_{56} + T_{12}}{2}$, of equation 7 is considered as the

baseline term. The effects of wind have been analyzed and a small correction factor can be employed if reliable wind data are available. The curvature of the front can be corrected for if it is assumed that the radius of curvature is equal to the charge distance. However, this is an extremely small effect at the distances used. Measurements have been made of the pressure remaining in the sound wave (1/2 lb. TNT at 200 ft.) and the results range from 0.1 to 0.3 psi. This causes pressure values as measured by the velocity method to be low by approximately that amount. When more data are available, a correction can be made for this finite pressure in the "sound" wave.

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Gage arrangement illustrating general case used
for computing derived pressure.



Top View
Figure 2

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Damage to Aircraft by Elast

TABLE IA

SUMMARY OF PRESSURES

<u>Detonation Number</u>	<u>Derived Pressure PSI</u>	<u>Impulse Lb. MSEC/IN²</u>
1	2.5	27
2	3.1	31
3	4.0*	34
4	4.7*	33
5	6.0*	42
6	5.5	44
7	7.7*	54
8	7.0	53
9	7.4	56
10	8.0	57
11	8.3	61
12	6.6	41
13	6.5	43
14	7.5	43
15	11.0	73
16	11.2	66
17	12.6	72
18	13.4*	67
19	11.1	55
20	15.0	64
21	11.2*	62
22	11.6*	52
23	13.4	57
24	13.8	66
25	17.6	98
26	15.6	--
27	17.4*	87
28	16.2	81
29	18.6	97
30	--	--
31	30.6	93

NOTES: (1) Pressure is derived from velocity gages except * which is upper edge-on gage reading (see Fig. 7 Appendix A) for comparison of derived and edge-on pressures)

(2) Impulse is that measured by the upper edge-on gage.

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APPENDIX B

TABLE IB

DAMAGE TO AIRCRAFT BY BLAST (F9F, RH)
SUMMARY OF PRESSURES (PSI)

Date 1952	Det.	R	W	R/(2W) ^{1/3}	Velocity Gages			Edge-on Gages		Face-on Gages	
					Derived	Upper, 1-2	Lower, 5-6	Upper	Lower	Upper	Lower
4/23	1	160	350	18.02	2.5	2.6	2.5	No Cal.	No Cal.	No. Cal.	No. Cal.
5/2	2	160	450	16.57	3.1	4.4	2.3	3.1	3.2	5.5-11.1	4.2-7.4
5/2	3	120	300	14.22	-	-	-	4.0	4.0	5.5-15.8	5.1-10.1
5/7	4	120	375	13.20	-	-	-	4.7	4.8	7.7-14.5	6.4-10.0
5/7	5	120	450	12.42	-	-	-	6.0	5.9	12.6-17.4	9.7-13.4
5/8	6	100	300	11.85	5.5	5.8	5.4	6.3	6.4	12.4-23.8	7.6-14.7
5/8	7	100	350	11.26	-	-	-	7.7	7.4	14.3-24.6	8.0-10.0
5/9	8	100	400	10.77	7.0	6.9	7.2	7.5	7.4	13.7-22.5	11.2-18.1
5/9	9	100	450	10.35	7.4	9.5	6.3	8.6	8.3	12.6-24.6	9.3-16.6
5/9	10	100	500	10.00	8.0	9.7	7.4	9.5	9.1	16.0-29.5	10.5-17.2
5/12	11	93	450	9.63	8.3	9.4	7.8	9.4	9.4	16.2-33.0	10.2-19.7
5/13	12	93	500	9.30	6.6	7.8	5.7	7.5	7.5	15.3-27.1	10.5-16.5
5/15	13	88	450	9.11	6.5	7.5	5.8	7.8	7.8	13.3-22.2	7.7-15.1
5/21	14	88	500	8.80	7.5	9.1	6.3	8.5	8.4	13.5-30.1	11.3-20.1
5/22	15	83	450	8.60	11.0	11.9	10.0	12.1	11.6	24.4-42.5	15.3-25.8
5/22	16	83	500	8.30	11.2	10.8	11.6	12.0	12.1	24.4-43.0	16.3-29.5
5/23	17	79	450	8.18	12.6	13.0*	12.4*	13.0	13.3	18.7-52.9	19.2-34.3
5/23	18	79	500	7.90	-	-	13.0	13.4	13.2	25.4-52.9	16.5-28.7
5/27	19	76	450	7.87	11.1	12.1	10.2	12.2	12.8	24.4-46.6	18.2-29.9
5/27	20	76	500	7.60	15.0	15.9	14.1	16.1	16.3	30.6-60.6	23.0-37.7
5/28	21	73.5	450	7.61	-	-	11.0	11.2	12.2*	No Cal.	No Cal.
5/28	22	73.5	500	7.35	-	-	10.6	11.6	-	23.9-41.4	14.0-24.5
5/28	23	70	450	7.25	13.4	13.9	12.9	14.2	-	37.9-64.2	21.9-37.8

NOTES:

- (1) R = Distance in feet from charge to mid-point between gages 1-2 and 5-6.
- (2) W = Charge weight in pounds of TNT.
- (3) * - These values are questionable due to a poor record.
- (4) Damage to the wing occurred on rounds Nos. 19, 20, 22 and 23.
- (5) Face-on gage values include the "Plateau" and "peak" measurements.

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TABLE IB (Continued)

Date 1952	Det.	R	W	$R/(2W)^{1/3}$	Velocity Gages			Edge-on Gages		Face-on Gages	
					Derived Upper, 1-2	Derived Lower, (lower)	Lower, 1-2	Upper	Lower	Upper	Lower
6/10	24	70	450	7.25	13.83	13.83	14.6	13.2	12.9	26.6-58.1	21.6-41.9
6/16	25	70	500	7.00	17.56	17.56	17.2	17.8	11.7*	46.4-88.8	35.8-50.3
6/17	26	67	450	7.06	15.65	15.65	16.9	-	-	-	-
6/20	27	67	500	6.70	-	19.38	20.0	17.4	14.2*	28.0-41.2	24.9-35.4
6/26	28	70	500	7.00	16.17	18.08	17.9	17.1	17.4	29.6-55.1	30.6 -
6/27	29	67	500	6.70	18.64	18.32	18.7	19.4	19.5	28.4-69.0	26.5-62.0
6/27	30	64	500	6.40	-	-	-	-	-	-	-
7/1	31	61	500	6.10	30.57	32.53	33.3	28.9	30.8	45.1-100.6	47.7- --

NOTES: (1) R = Distance in feet from charge to mid-point between gages 1-2, 1-3, and 5-6, 5-7.
(2) W = Charge weight in pounds of TNT.
(3) Face-on gage values include the "plateau" and "peak" measurements.
(4) * These values are questionable.
(5) New gage stands of same height on detonations No. 27 through 31.
(6) Wing (F9F, RH) replaced by wing (F9F, LH) on detonations No. 28 through 31.
(7) Damage occurred to wing F9F, LH on all detonations.

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TABLE II

VALUES OF DISTANCES, CHARGE WEIGHTS AND PRESSURES

Date 1952	Det.	R	W	Pressures, PSI						
				1-2	2-3	3-4	5-6	6-7	7-8	6-8
4/23	1	160	350	2.6	2.4	---	2.5	2.3	---	
5/2	2	160	450	4.4	4.3	4.0	2.3	2.5	2.3	
5/2	3	120	300	---	---	---	---	---	---	
5/7	4	120	375	---	---	---	---	---	---	
5/7	5	120	450	---	---	---	---	---	---	
5/8	6	100	300	5.8	5.2	5.1	5.4	4.5	4.8	
5/8	7	100	350	---	---	---	---	---	---	
5/9	8	100	400	6.9	6.5	6.2	7.2	7.0	6.3	
5/9	9	100	450	9.5	8.7	8.0	6.3	6.2	5.9	
5/9	10	100	500	9.7	9.0	8.2	7.4	7.2	6.7	
5/12	11	93	450	9.4	9.6	8.0	7.8	7.4	6.7	
5/13	12	93	500	7.8	7.1	6.5	5.7	5.6	5.2	
5/15	13	88	450	7.5	6.6	5.8	5.8	---	---	5.6
5/21	14	88	500	9.1	8.1	7.5	6.3	6.7	6.2	
5/22	15	83	450	11.9	10.7	10.0	10.0	9.9	8.7	
5/22	16	83	500	10.8	10.8	9.9	11.6	11.0	9.7	
5/23	17	79	450	13.0*	11.9*	---	12.4*	12.5*	---	
5/23	18	79	500	----	----	---	13.0	12.2	11.0	
5/27	19	76	450	12.1	11.1	10.3	10.2	10.1	9.5	
5/27	20	76	500	15.9	14.1	12.6	14.1	13.4	11.9	
5/28	21	73.5	450	----	----	10.2	11.0	----	----	
5/28	22	73.5	500	----	9.2	9.2	10.6	9.2	8.4	
5/28	23	70	450	13.9	11.8	11.3	12.9	11.4	10.9	

- NOTES: (1) R = Distance in feet from charge to mid-point between gages 1-2.
 (2) W = Weight of charge in pounds of TNT.
 (3) Intervals 1-2, 2-3, 3-4, Upper Velocity Gages.
 (4) Intervals 5-6, 6-7, 7-8, Lower Velocity Gages.
 (5) * These values are questionable due to a poor record.

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Damage to Aircraft by Blast

TABLE II (Continued)

Date 1952	Det.	R	W	Pressures, PSI						
				1-2	2-3	3-4	5-6	6-7	7-8	5-7
6/10	24	70	450	13.3	11.8	10.3	14.6	12.8	11.7	
6/16	25	70	500	17.8	16.0	14.0	17.2	16.1	14.5	
6/17	26	67	450	15.7	13.4	11.3	--	--	13.2	16.9
				(1-3)			(5-7)			
6/20	27	67	500		--		20.0			
6/26	28	70	500		17.0		17.9			
6/27	29	67	500		19.3		18.7			
6/27	30	64	500		--		--			
7/1	31	61	500		32.4		33.3			

- NOTES: (1) R = Distance in feet from charge to mid-point between gages 1-2, 5-6 and (1-3), (5-7).
 (2) W = Weight of charge in pounds of TNT.
 (3) Intervals 1-2, 2-3, 3-4 and (1-3), Upper Velocity Gages.
 (4) Intervals 5-6, 6-7, 7-8 and (5-7), Lower Velocity Gages.
 (5) New gage stands of same height on detonations No. 27 through 31.
 (6) Wing (F9F, RH) replaced by Wing (F9F, LH) on detonations No. 28 through 31.
 (7) Damage occurred to wing F9F, LH on all detonations.

TABLE III

VALUES OF DISTANCES, WEIGHTS OF CHARGES, PRESSURES (PSI),
POSITIVE TIME DURATIONS AND IMPULSES

Date	Det.	R	W	Upper Edge-On			Lower Edge-On			Upper Face-On			Lower Face-On		
				PSI	Dura- tion	Impulse	PSI	Dura- tion	Impulse	PSI	Dura- tion	Impulse	PSI	Dura- tion	Impulse
4/23	1	160	350	No Cal.	21	27	No Cal.	21	26	No Cal.	21	26	No Cal.	21	26
5/2	2	160	450	3.1	20	31	3.2	20	32	5.5-11.1	20	32	4.2-7.4	20	32
5/2	3	120	300	4.0	17	34	4.0	15	30	5.5-15.8	17	30	5.1-10.1	15	30
5/7	4	120	375	4.7	14	33	4.8	14	34	7.7-14.5	14	34	6.4-10.0	14	34
5/7	5	120	450	6.0	14	42	5.9	14	41	12.6-17.4	14	41	9.7-13.4	14	41
5/8	6	100	300	6.3	14	44	6.4	15	48	12.4-23.8	15	48	7.6-14.7	15	48
5/8	7	100	350	7.7	14	54	7.4	13	48	14.3-24.6	14	48	8.0-10.0	13	48
5/9	8	100	400	7.5	14	53	7.4	14	52	13.7-22.5	14	52	11.2-18.1	14	52
5/9	9	100	450	8.6	13	56	8.3	14	58	12.6-24.6	13	58	9.3-16.6	13	58
5/9	10	100	500	9.5	12	57	9.1	12	55	16.0-29.5	12	55	10.5-17.2	12	55
5/12	11	93	450	9.4	13	61	9.4	13	61	16.2-33.0	13	61	10.2-19.7	13	61
5/13	12	93	500	7.5	11	41	7.5	11	41	15.3-27.1	11	41	10.5-16.5	11	41
5/15	13	88	450	7.8	11	43	7.8	11	43	13.3-22.2	11	43	7.7-15.1	11	43
5/21	14	88	500	8.5	10	43	8.4	11	46	13.5-30.1	11	46	11.3-20.1	11	46
5/22	15	83	450	12.1	12	73	11.6	12	70	24.4-42.5	12	70	15.3-25.8	12	70
5/22	16	83	500	12.0	11	66	12.1	11	73	24.4-43.0	11	73	16.3-29.5	11	73
5/23	17	79	450	13.0	11	72	13.3	11	73	18.7-52.9	11	73	19.2-34.3	11	73
5/23	18	73	500	13.4	10	67	13.2	10	66	25.4-52.9	10	66	16.5-28.7	10	66
5/27	19	76	450	12.2	9	55	12.8	10	64	24.4-46.6	10	64	18.2-29.9	10	64
5/27	20	76	500	16.1	8	64	16.3	8	65	30.6-60.6	9	65	23.0-37.7	9	65
5/28	21	73.5	450	11.2	11	62	12.2*	12	73	No Cal.	11	73	No Cal.	12	73
5/28	22	73.5	500	11.6	9	52	-	10	53	23.9-41.4	10	53	14.0-24.5	10	53
5/28	23	70	450	14.2	8	57	-	10	65	37.9-64.2	9	65	21.9-37.8	10	65

NOTES:

R - Distance in feet from charge to mid-point between velocity gages 1-2 and 5-6.

W - Weight of charge in pounds of TNT.

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Damage to Aircraft by Blast

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TABLE III (Continued)

Date 1952	Det.	R	W	Upper Edge-On		Lower Edge-On		Upper Face-on		Lower Face-On	
				PSI	Dura- tion	Impulse	PSI	Dura- tion	Impulse	PSI	Dura- tion
6/10	24	70	450	13.2	10	66	12.9	10	61	21.6, 41.9	10
6/16	25	70	500	17.8	11	98	11.7	11	64	35.8, 50.3	11
6/17	26	67	450	-	-	-	-	-	-	-	-
6/20	27	67	500	17.4	10	87	14.2	11	78	24.9, 35.4	11
6/26	28	70	500	17.1	9.5	81	17.4	9.5	83	30.6, --	9.5
6/27	29	67	500	19.4	10	97	19.5	9.5	93	26.5, 62.0	9.5
6/27	30	64	500	-	-	-	-	-	-	-	-
7/1	31	61	500	28.9	6.5	93	30.8	7.0	108	45.1, 100.6	5.5
										47.7, --	6.5

NOTES:

- (1) R = Distance in feet from charge to mid-point between Velocity Gages 1-2, 1-3, 5-6, and 5-7.
- (2) W = Weight of charge in pounds of TNT.
- (3) Duration = Positive time duration in milliseconds.
- (4) Impulse = Lbs Ms/Sq. In.
- (5) Face-on gage values include the "plateau" and "peak" measurements.

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Damage to Aircraft by Blast

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TABLE IV

FUNCTIONS OF IMPULSE, DISTANCES AND CHARGE WEIGHTS

Date 1952	Det.	R	W	Upper Edge-On		Lower Edge-On	
				Impulse	$I/(2W)^{1/3}$	Impulse	$I/(2W)^{1/3}$
4/23	1	160	350	27	3.04	26	2.93
5/2	2	160	450	31	3.21	32	3.31
5/2	3	120	300	34	4.03	30	3.56
5/7	4	120	375	33	3.63	34	3.74
5/7	5	120	450	42	4.35	41	4.25
5/8	6	100	300	44	5.21	48	5.69
5/8	7	100	350	54	6.08	48	5.41
5/9	8	100	400	53	5.71	52	5.60
5/9	9	100	450	56	5.80	58	6.01
5/9	10	100	500	57	5.70	55	5.50
5/12	11	93	450	61	6.32	61	6.32
5/13	12	93	500	41	4.10	41	4.10
5/15	13	88	450	43	4.45	43	4.45
5/21	14	88	500	43	4.30	46	4.60
5/22	15	83	450	73	7.56	70	7.25
5/22	16	83	500	66	6.60	73	7.30
5/23	17	79	450	72	7.46	73	7.56
5/23	18	79	500	67	6.70	66	6.60
5/27	19	76	450	55	5.70	64	6.63
5/27	20	76	500	64	6.40	65	6.50
5/28	21	73.5	450	62	6.42	73	7.56
5/28	22	73.5	500	52	5.20	53	5.30
5/28	23	70	450	57	5.90	65	6.73

NOTES: (1) Positive Impulse, $I/(2W)^{1/3}$ in PSI - MSEC/LB^{1/3}

(2) Distance, $R/(2W)^{1/3}$ in FT./LB.^{1/3}

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Damage to Aircraft by Blast

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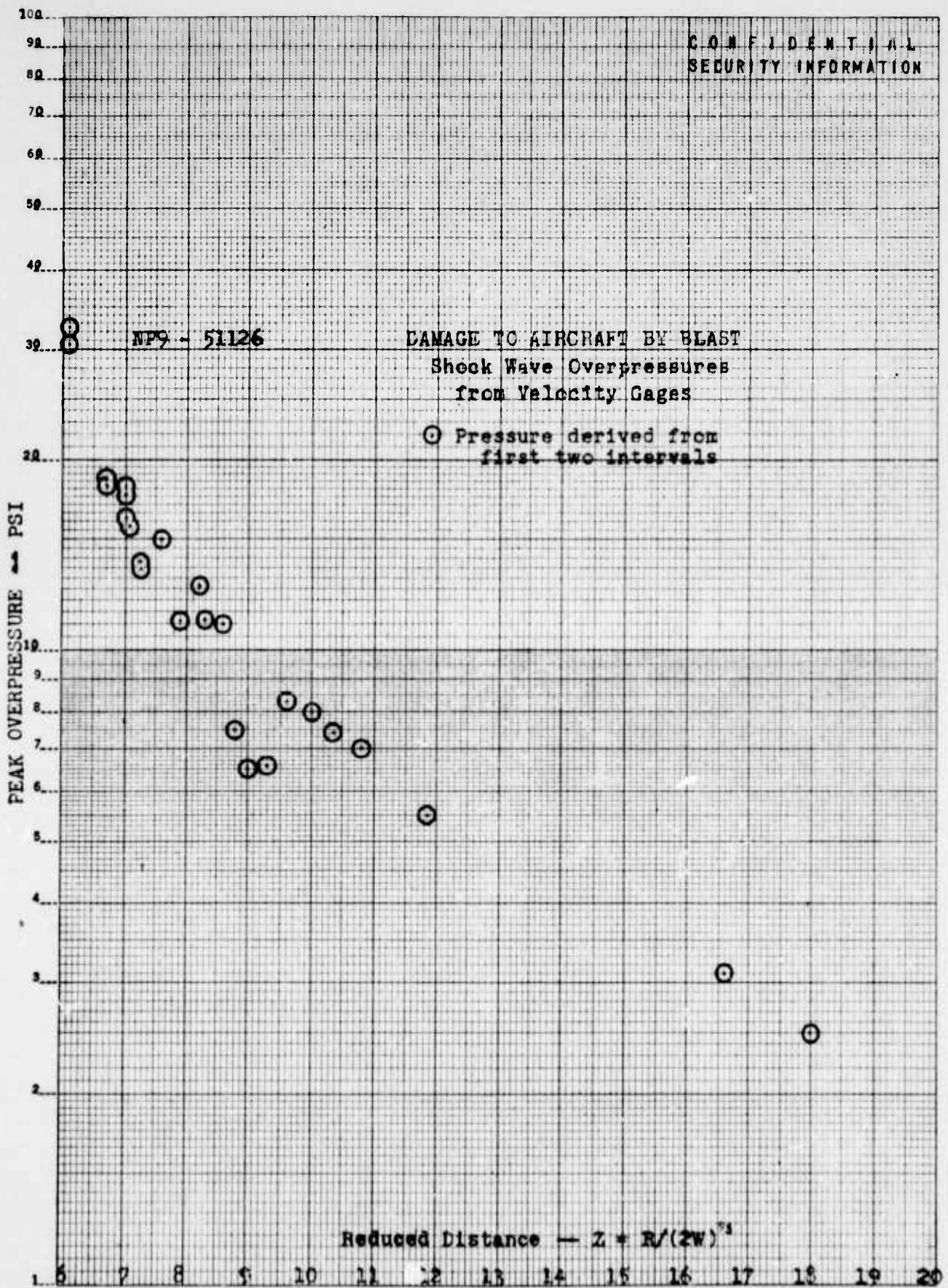
TABLE IV (Continued)

Date	Det.	R	W	Upper Edge-On		Lower Edge-On	
				Impulse	$I/(2W)^{1/3}$	Impulse	$I/(2W)^{1/3}$
1952							
6/10	24	70	450	66	6.84	61	6.32
6/16	25	70	500	98	9.80	64*	6.40
6/17	26	67	450	-	-	-	-
6/20	27	67	500	87	8.70	78*	7.80
6/26	28	70	500	81	8.10	83	8.30
6/27	29	67	500	97	9.70	93	9.30
6/27	30	64	500	-	-	-	-
7/1	31	61	500	93	9.30	108	10.80

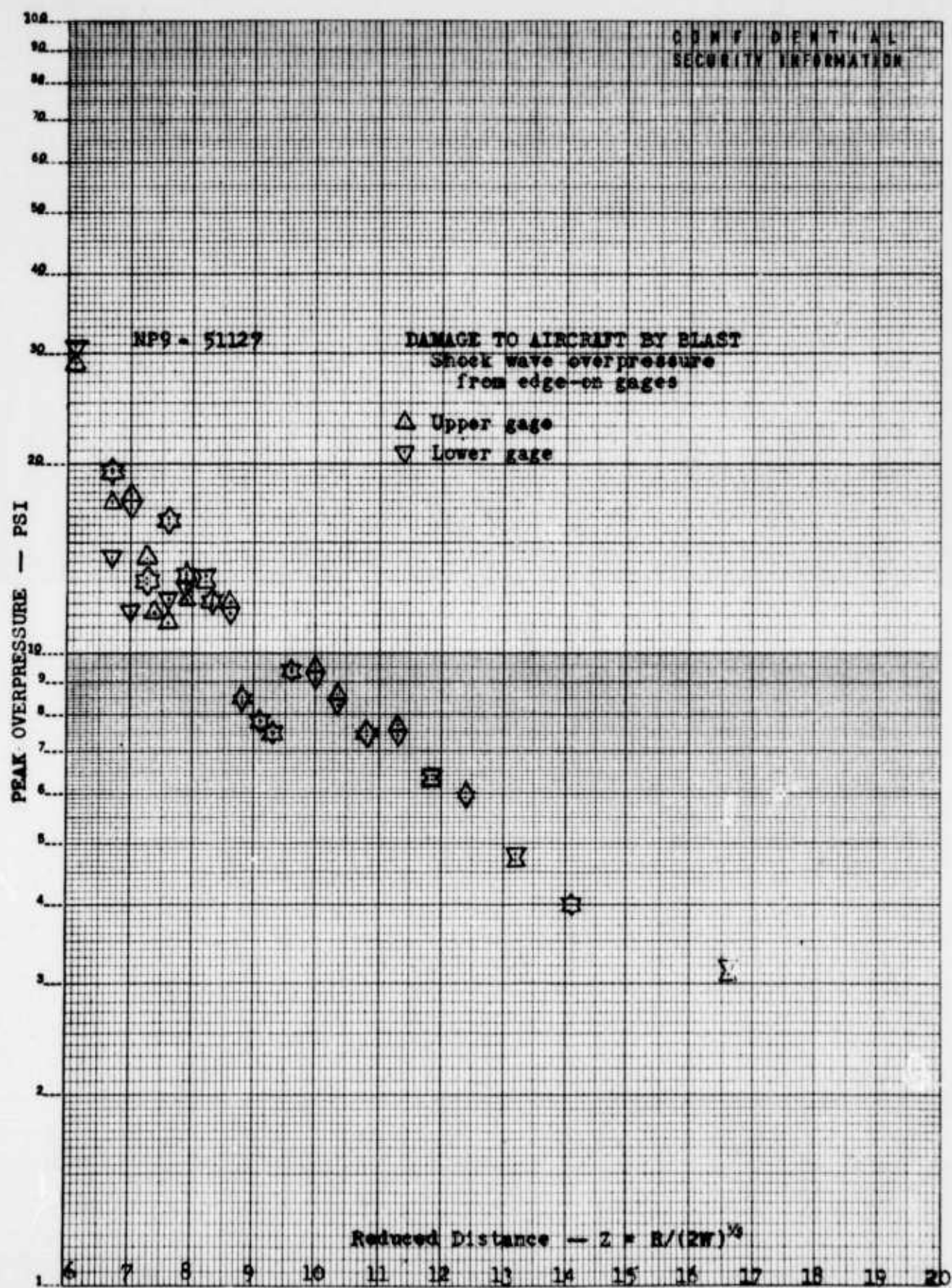
NOTES: (1) Positive Impulse, $I/(2W)^{1/3}$ in PSI - MSEC/LB^{1/3}(2) Distance, $R/(2W)^{1/3}$ in Ft./ Lb.^{1/3}

(3) * - This value is questionable.

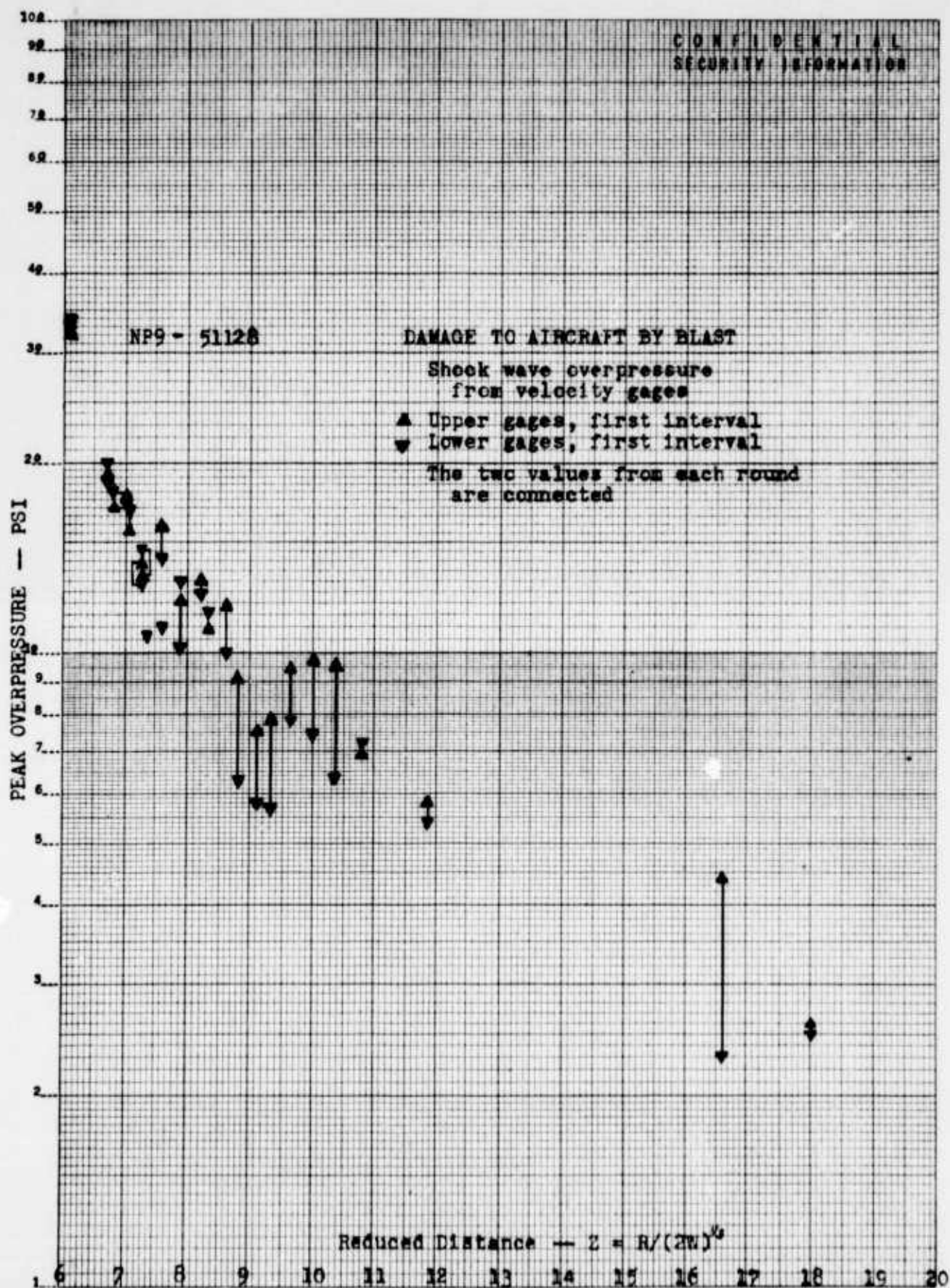
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APPENDIX B FIG 3



APPENDIX P FIG 4



APPENDIX B FIG 5

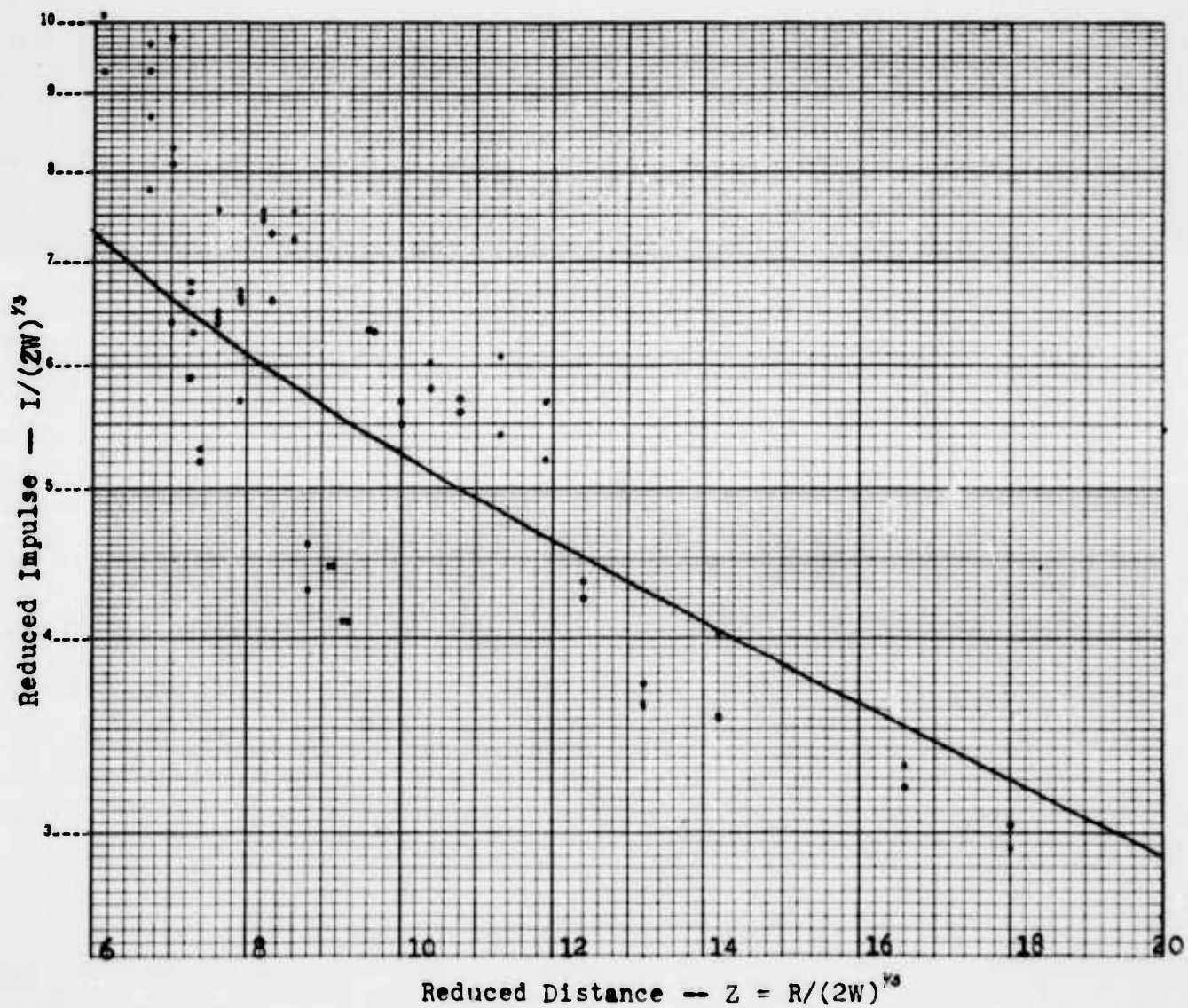
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NP9 - 51129

DAMAGE TO AIRCRAFT BY BLAST
Positive impulse vs. distance

Data from edge-on gages

- Theoretical curve from OSRD
summ. tech. rept., div. 2,
NDRC — for comparison with
observed data

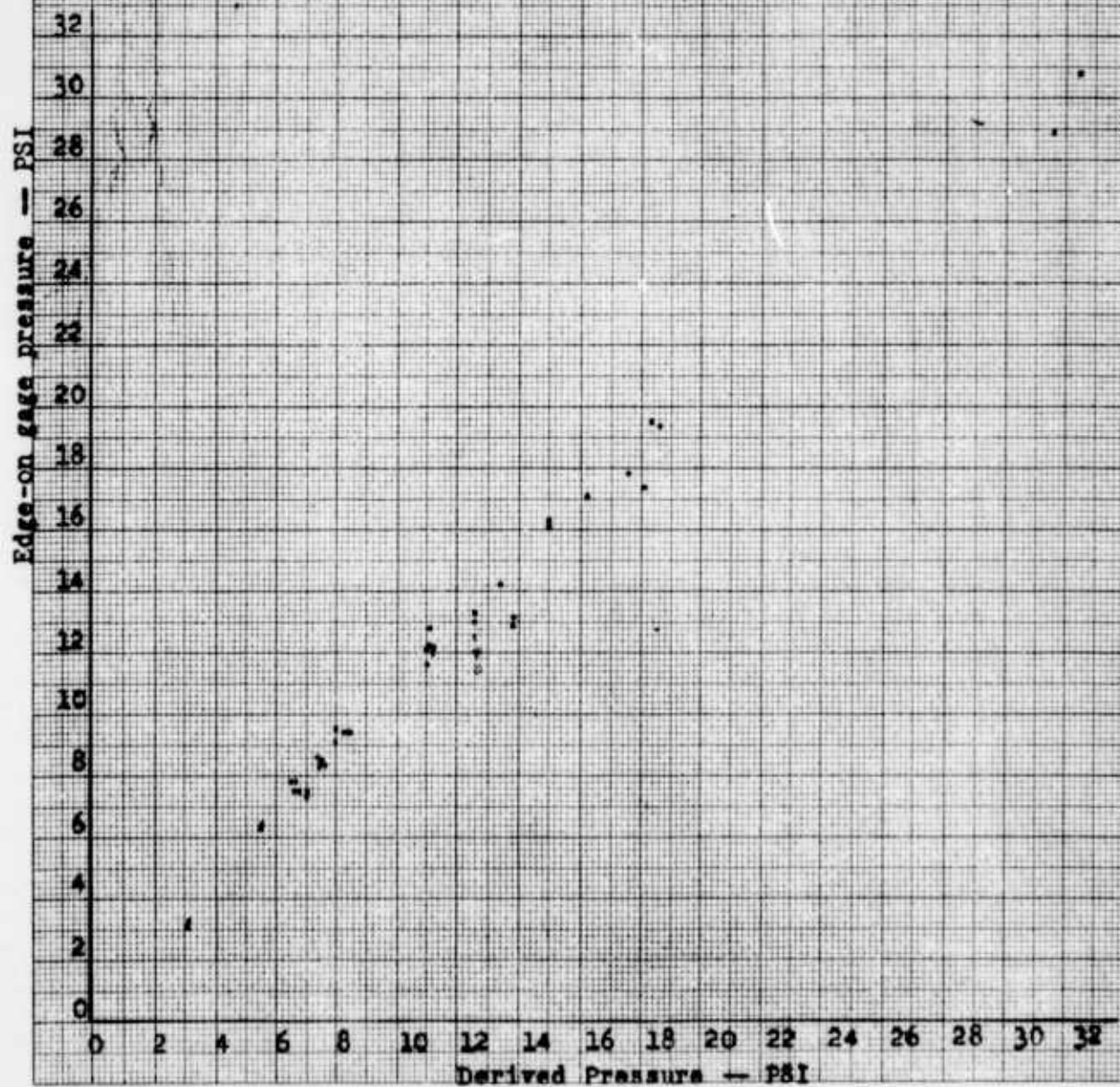


Appendix B FIG 6

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79-51130

DAMAGE TO AIRCRAFT BY BLAST
Comparison of edge-on pressures
with pressures derived from
velocity



APPENDIX B

FIG 7

NP9-49362

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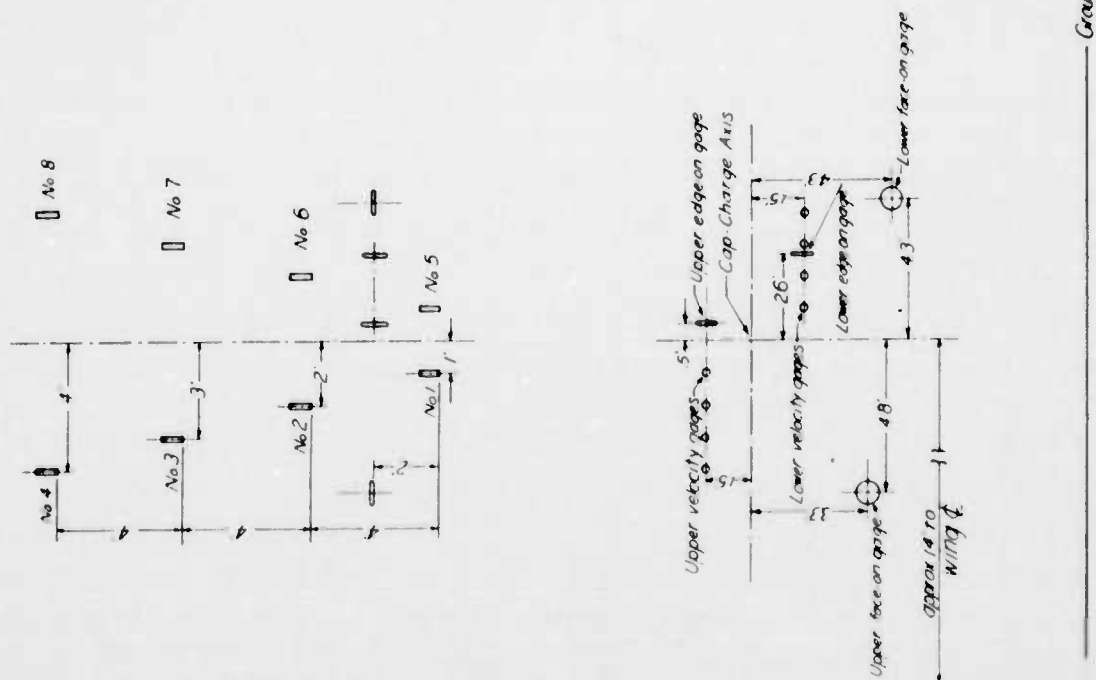


Figure 8

Gauge No. 1 was tilted so that
line was coincident with the
Cap Charge Axis

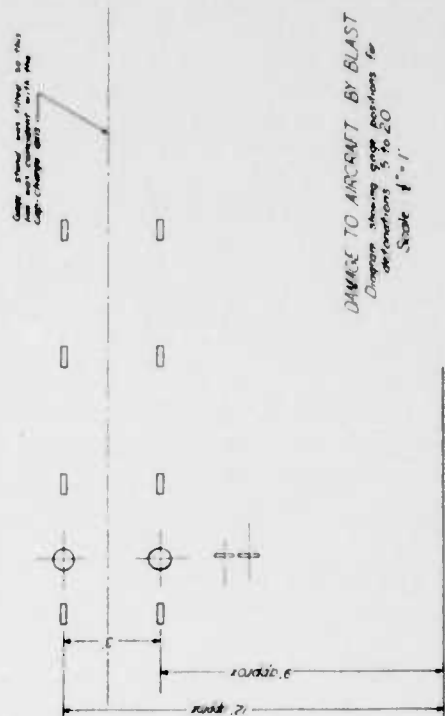
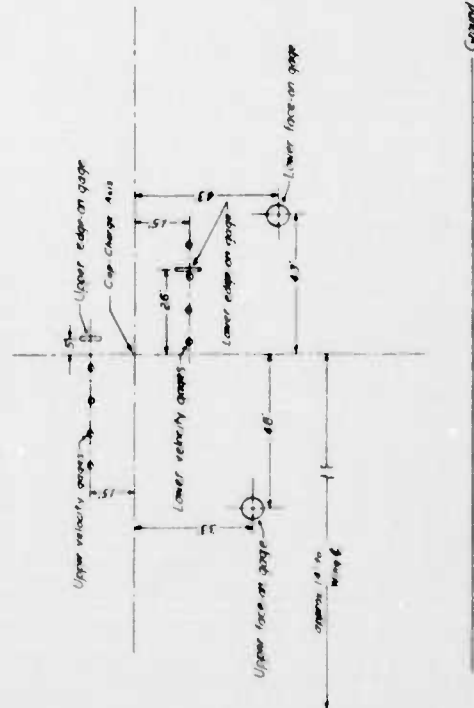
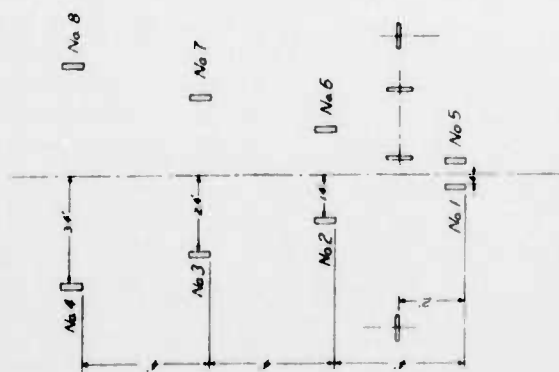
DAMAGE TO AIRCRAFT BY BLAST
Diagram showing gauge positions for
detonations 1 to 4
Scale 1/4" = 1'

DIAGRAM NO. 1

NP9-49342

NP9-49342

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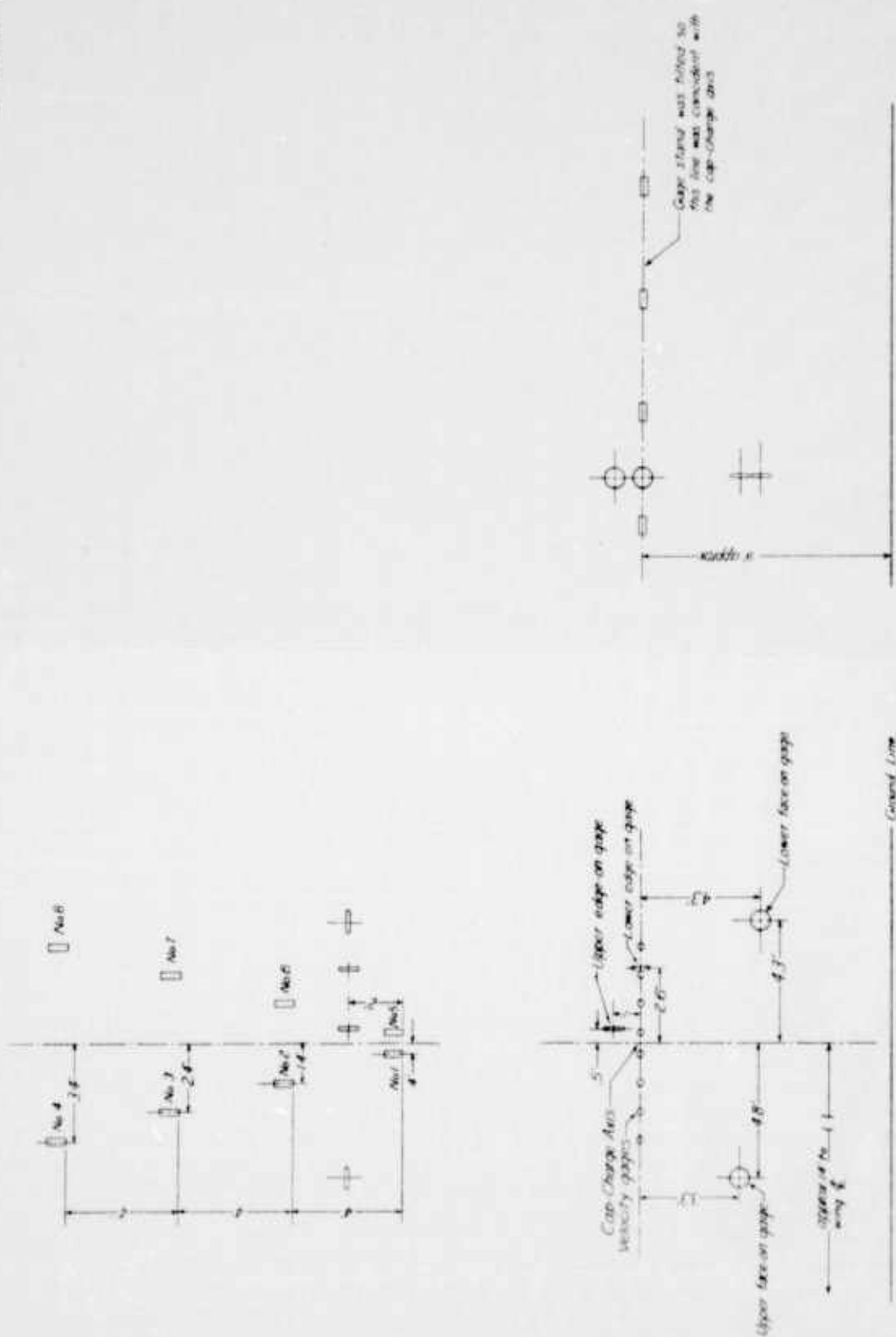
DAWSE TO AIRCRAFT BY BLAST
Diagram showing gauge positions for
deflections 5 to 20
Scale 1"=1'

DIAGRAM NO 2

Figure 9

NP9- 363

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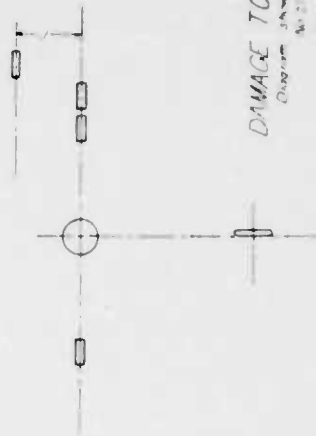
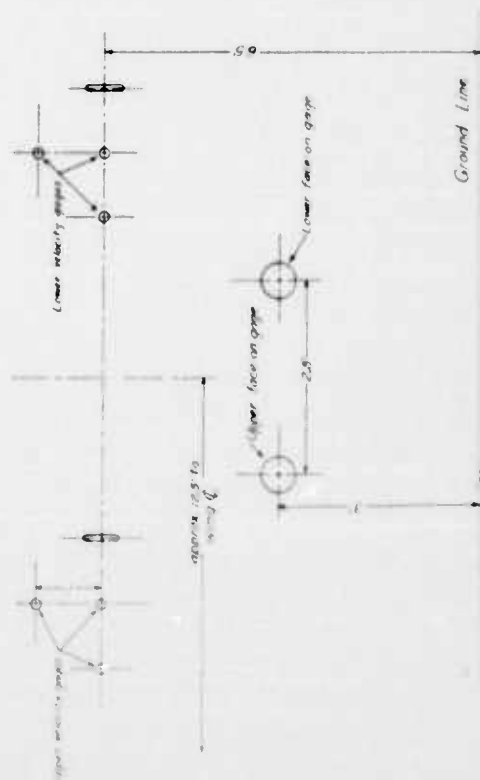
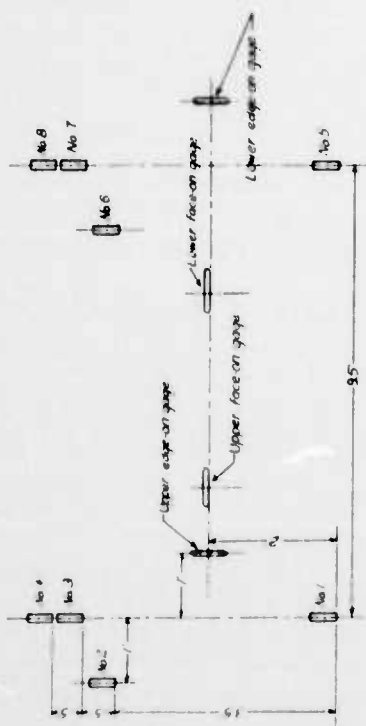


DAMAGE TO AIRCRAFT BY BLAST
Diagram showing gap positions for
deflections of 1/2 in. 1/4 in.
Scale 1/4" = 1'

Figure 10

NP9-51106

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DAMAGE TO AIRCRAFT BY BLAST
Diagram No. 22 to A-27
Scale 1"=1'

Ground Line

Figure 11

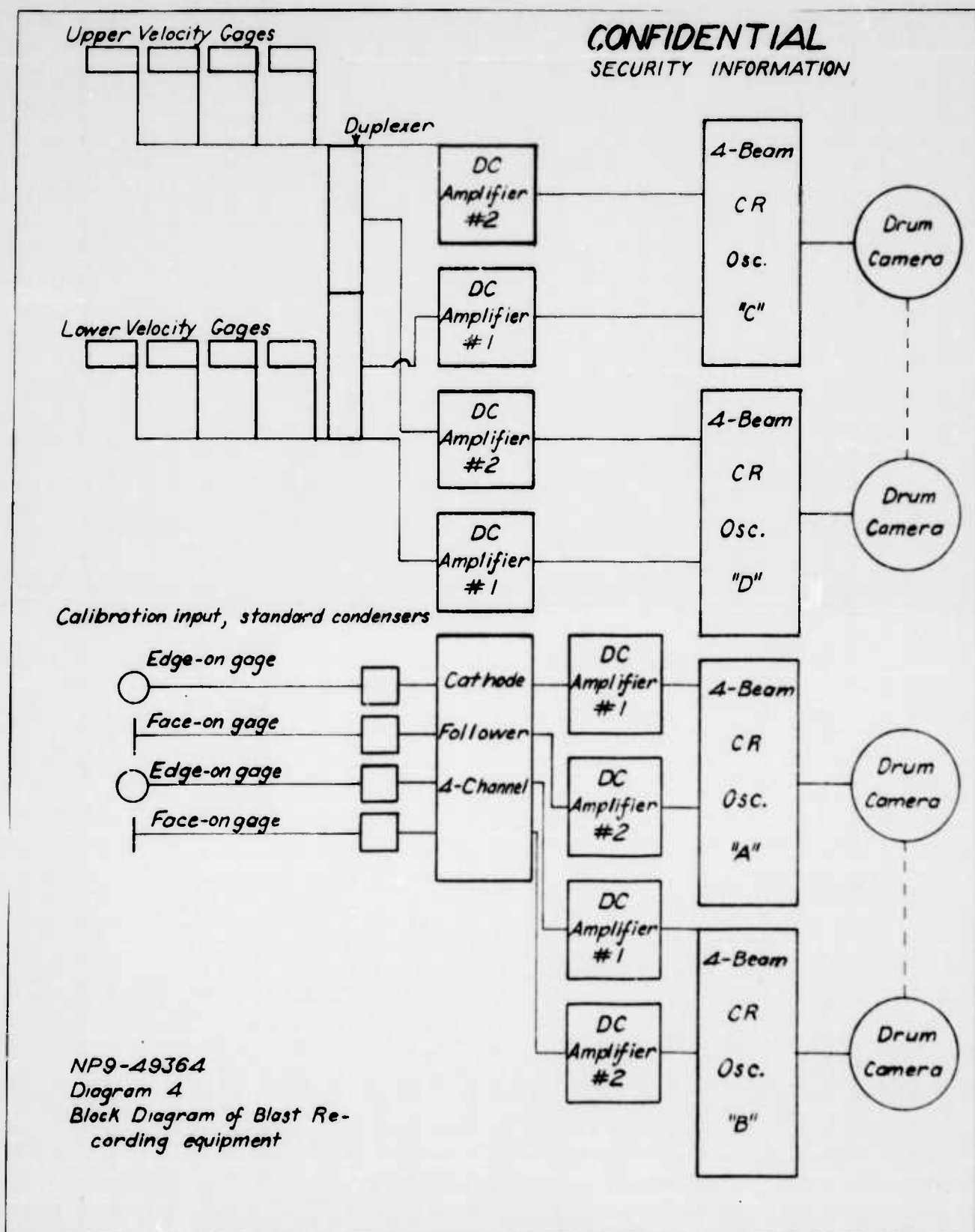
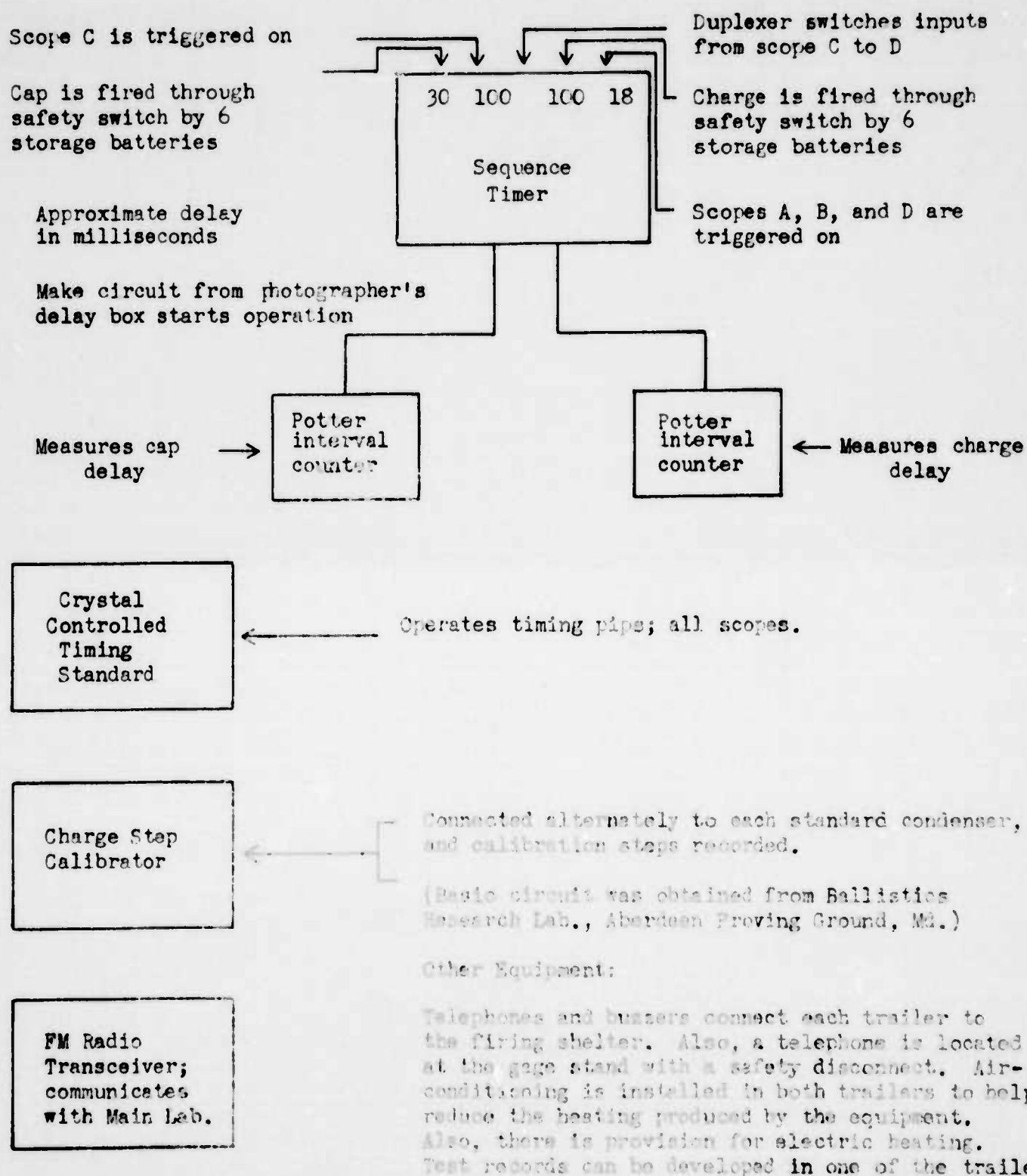


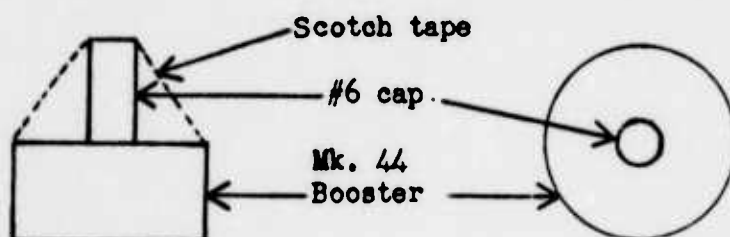
Figure 12

Damage to Aircraft by Blast



Damage to Aircraft by Blast

In detonations 1 - 24, a #6 blasting cap and Mk. 44 Booster were taped together so as to be symmetrical about the vertical axis.



The cap assembly was hung from a vertical pipe 50' from the first velocity interval, with a 1-foot right-angle pipe fixed to the top so that the cap would clear the vertical pipe.

It should also be noted that on detonations 2 and 3 a special engineer's cap was used to try to reduce the slight overpressure (.2 psi estimated) from the #6 cap and Mk. 44 booster. However, this was not satisfactory as the records were too small to evaluate.

DETONATIONS 25 - 31:

The above cap arrangement was changed to 1/2 pound block of TNT detonated by a special engineer's blasting cap at 200 feet from the first velocity interval because detonation No. 24 blew the cap support into the gage array. It turned out that the 1/2 lb. TNT gave a cleaner, sharper, and more reproducible signal at a slightly lower pressure than the first arrangement.

NP9 49449
 19 June 1952
 DAMAGE TO AIRCRAFT BY BLAST - Configuration of TNT demolition blocks used in detonations. All charges were placed on a wooden stand five (5) feet above a steel plate. The position of the boosters is indicated by a space left between the blocks. The numbers are in chronological order of detonation.

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Diagram 7

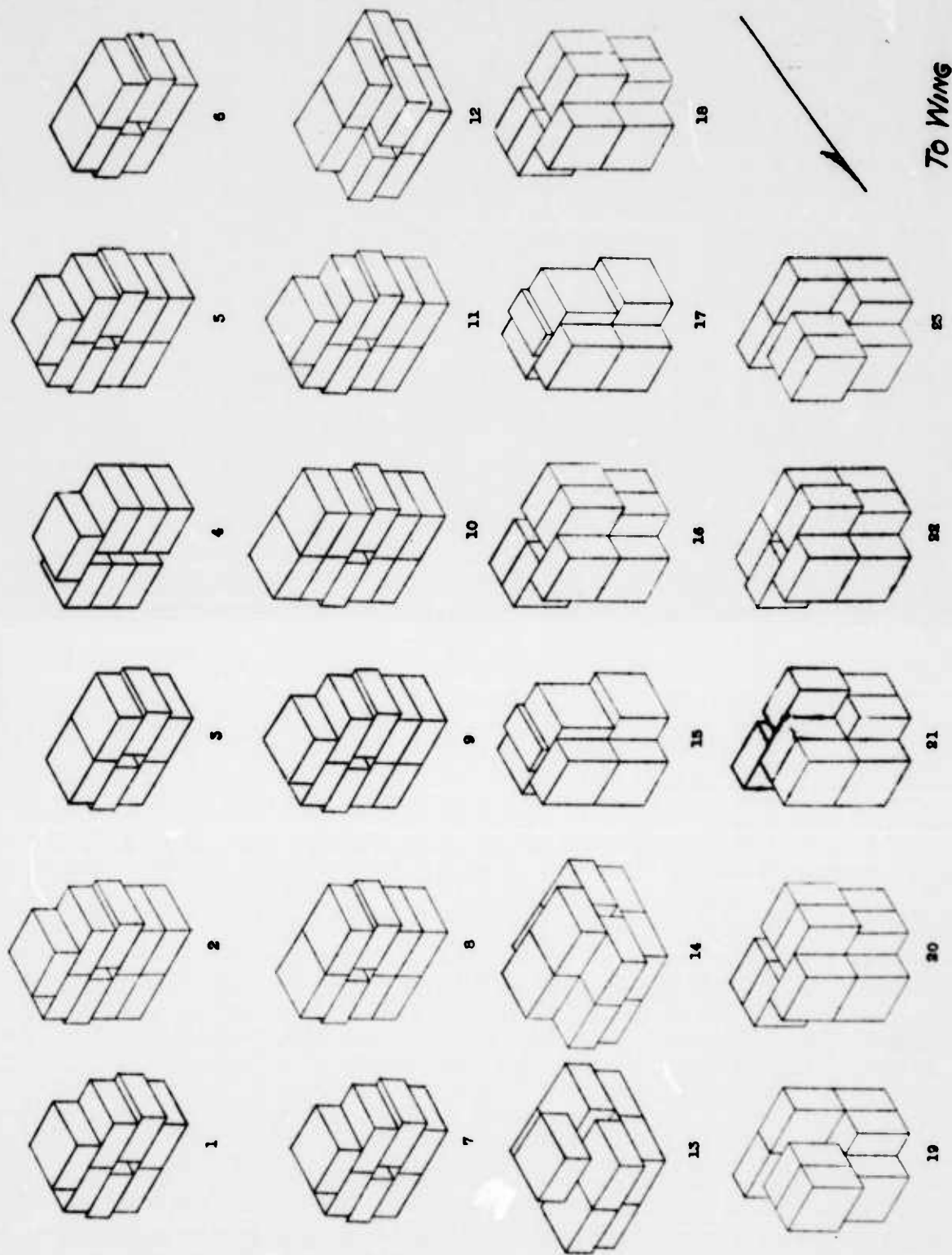


Figure 15

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Damage to Aircraft by Blast

TABLE V

MAIN CHARGE DATA

<u>Det. No.</u>	<u>Distance from Wing (ft)</u>	<u>Weight of Charge (lbs.)</u>	<u>Approximate Charge Shape (see Figure 15)</u>	<u>Direction of Normal to Charge Face</u>	<u>Remarks</u>
1	160	350	Wall	Toward Wing	
2	160	450	"	" "	
3	120	300	"	" "	See Note 6
4	120	375	"	" "	" " 3
5	120	450	"	" "	" " 4
6	100	300	"	" "	
7	100	350	"	" "	
8	100	400	"	" "	
9	100	450	"	" "	
10	100	500	"	" "	
11	93	450	"	" "	
12	93	500	Flat Distribution	" "	
13	88	450	" "	" "	
14	88	500	" "	Midway between	
15	83	450	Cylinder	Wing & Gages	
16	84	500	"	" "	
17	79	450	"	Toward Gages	
18	79	500	"	" "	
19	76	450	"	" "	
20	76	500	"	" "	
21	73.5	450	"	" "	
22	73.5	500	"	" "	
23	70	450	"	" "	
24	70	450	" Same as 21	" "	
25	70	500	" Same as 22	" "	
26	67	450	" Same as 15	" "	
27	67	500	" Same as 22	" "	
28	70	500	" Same as 22	" "	
29	67	500	" Same as 22	" "	
30	64	500	" Same as 22	" "	
31	61	500	" Same as 22	" "	

NOTES:

1. The charge was placed on a 5 ft. wooden stand and so arranged that fragments would not be thrown toward the wing.

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Damage to Aircraft by Blast
-----TABLE V (Continued)

2. The charge was made of 49-lb. blocks of cast TNT-A Mk. 14 Mod. 1. Figure 15 shows the way it was placed for each detonation.
3. Detonation No. 4 had 25 one-pound blocks in addition to those shown on the drawing. Also, one of these blocks was used for a booster.
4. Detonation No. 5 had 6 one-pound blocks of TNT in addition to those shown and one of these was used for a booster. All the other detonations had a one-pound block of comp. C (m3) for a booster.
5. All the detonations were centrally initiated with a special engineers cap placed in the booster in the center of the charge.
6. On all detonations except No. 3, a 6" thick armor plate was placed on the ground under the charge stand. No plate was used on detonation No. 3.

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Damage to Aircraft by Blast

TABLE VI

Location of Blast Gages

<u>Det. No.</u>	<u>Dist. from Chg. to Center of First Interval</u>	<u>Upper Edge-on Gage No.</u>	<u>Lower Edge-on Gage No.</u>	<u>Upper Face-on Gage No.</u>	<u>Lower Face-on Gage No.</u>	<u>Remarks</u>
1	160	10	11	3 Op.	7 No.	See Figure 8
2	160	10	11	3 "	7 "	" " 8
3	120	10	11	3 "	7 "	" " 8
4	120	10	11	3 "	7 "	" " 8
5	120	10	11	3 "	7 "	" " 9
6	120	10	11	4 "	7 "	" " 9
7	100	10	11	4 "	7 "	" " 9
8	100	10	11	4 "	7 "	" " 9
9	100	10	11	4 "	7 "	" " 9
10	100	10	11	4 "	7 "	" " 9
11	93	10	11	4 "	7 "	" " 9
12	93	10	11	4 "	7 "	" " 10 & 9
13	88	10	11	4 "	5 Op.	" " 10 & 9
14	88	10	11	4 "	5 "	" " 9
15	83	10	11	4 "	5 "	" " 9
16	84	10	11	4 "	5 "	" " 9
17	79	10	11	4 "	5 "	" " 9
18	79	10	11	4 "	5 "	" " 9
19	76	10	11	4 "	5 "	" " 9
20	76	10	11	4 "	5 "	" " 9
21	73.5	10	11	3 "	5 "	" " 10
22	73.5	10	11	3 "	5 "	" " 10
23	70	10	11	3 "	5 "	" " 10
24	70	10	11	4 "	5 "	" " 10
25	70	10	11	4 "	5 "	" " 10
26	67	10	11	4 "	5 "	" " 10
27	67	10	11	126	120	" " 11
28	70	10	7	97	127	" " 11
29	67	10	7	97	127	" " 11
30	64	10	7	97	127	" " 11
31	61	10	7	97	127	" " 11

NOTE:

1. For detonations 1 - 26, double faced Piezo-electric gages were used but the rear face was covered by a plate and gasket. "No." and "Op." refer to the numbered side of the gage and the side opposite the number respectively, and thus indicate which side was facing the charge.

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APPENDIX C

Damage to Aircraft by Blast
-----TABLE VIIGENERAL NOTES AND DEFINITIONS

1. All pressure-time blast gages were placed at the same radial distance as the front of the wing. (This is defined as the charge distance.)
2. The bisection of the angle formed by the 2 lines of velocity gages was on a radial line from the center of the charge. At the center of the first interval, this line was approximately 14 feet from the center of the wing.
3. The sound velocity cap was in a direct line with the charge and the center of the velocity gage array.
4. All computations of pressure used the correction for the current atmospheric pressure and considered the sound velocity cap velocity interval equal to the true sound velocity interval.
5. The edge-on gage pressures are obtained from a static calibration, which was supplied by the manufacturer (Cambridge Thermionic Corp.) and a charge step calibration was used for each detonation.
6. Impulse is here defined to be one-half the product of the edge-on pressure and the duration of the positive phase of the particular gage used.
7. The relation used to compute the shock pressure from the edge-on gages is as follows: $P_s = \frac{D_s}{D_c} \cdot \frac{C_c V_c}{KA}$

Where D_s = Signal deflection,

D_c = Calibration step deflection,

C_c = Capacity of calibration condenser (mmf),

V_c = Voltage of calibration step (volts),

KA = Static calibration of gage (mm Q/PSI),

and P_s = Overpressure (psi).

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Damage to Aircraft by Blast

TABLE VIII

Atmospheric Conditions

<u>Detona- tion</u>	<u>Temp. °F</u>	<u>Relative Hum. %</u>	<u>Direct'n</u>	<u>Wind Vel. Knots</u>	<u>Time</u>	<u>Po</u>
1	88	33	SW	8	1500	14.672
2	73	57	E,NE	3	1120	14.577
3	78	41	NE	6	1430	14.565
4	61	42	NW	10	1115	14.722
5	72	33	NW	10	1510	14.689
6	63	44	E,SE	4	1430	14.666
7	64	65	E,SE	5	1530	14.645
8	69	43	SE	8	1430	14.649
9	69	43	SE	7	1500	14.649
10	70	46	SE	7	1530	14.637
11	63	39	SW	10	1430	14.601
12	65	44	W,NW	10	1430	14.621
13	84	43	SW	18	1445	14.578
14	75	44	W	13	1515	14.657
15	71	52	NW	10	1130	14.786
16	75	36	W	8	1400	14.771
17	70	56	E,SE	2	1130	14.806
18	75	58	S,SE	4	1400	14.806
19	77	36	NW	5	1415	14.756
20	79	37	NW	4	1500	14.748
21	80	47	SW	7	1130	14.732
22	82	42	S	8	1430	14.732
23	84	43	SW	5	1500	14.724
24	83	66	WSW	10	1530	14.613
25	85	73	ESE	8	1550	14.693
26	92.2	59	SW	8	1500	14.616
27	78.9	40	SE	5	1445	14.761
28	98.4	50	W	5	1435	14.666
29	93.8	60	NNW	5	1155	14.713
30	97	52	N	2	1445	14.701
31	72.1	49	E	14	1045	14.762

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APPENDIX C

Damage to Aircraft by Blast
-----DESCRIPTION OF BLAST AREA, CAMERA LAYOUT, AND
METHOD OF WING ATTACHMENT

The overall layout of the blast area may be seen in Figure 16. This drawing shows relative positions of blast site, structure supports, gage stand, camera positions, instrument trailer positions and barricades. The photograph in Figure 17 shows the blast area as seen from the charge site 160 feet in front of the wing under surface. The position of the wing relative to the gage stand and the concrete foundation slab is shown in Figure 18.

Three high speed 16mm Fastax cameras were used for each detonation. Their positions are shown in Figure 16. Camera No. 1, at the 90° position relative to the line connecting the wing and the blast, was used to show the overall bending of the wing and had a 2 inch focal length lens. Camera No. 2 shows the bottom surface of the wing and the "harp" set-up to show the passage of the blast wave. This camera lens has a focal length of 2 inches. Camera No. 3 shows a close-up view of the wing surface and has a focal length of 6 inches. A 1,000 cycle timing source was used to print timing marks on the edge of the 16mm Fastax film. These marks are alternately light and dark, corresponding to the positive and negative peaks of the 1,000 cycle time source. This tuning fork timer is accurate to better than ±2 cycles in 1,000.

The right hand outer wing panel from the F9F aircraft was the first structure used. The wing was mounted on the concrete slab foundation by means of its attachment fittings and adapter plates so that a line normal to the under surface at the center of the wing would intersect the center of the demolition charge. No ailerons or flaps were available for this wing. The folding leading edge was not restrained rigidly to the wing, but allowed to swing forward under the negative pressure of the blast. On the second (LH) wing panel the leading edge was elastically restrained by means of a coil spring with a pull of about 75 pounds (initial tension).

The wing panels were secured to a 1 inch thick section of 2 feet by 4 feet armor plate as shown in Figure 19, which in turn was clamped to rails imbedded in the concrete slab. Three blocks of armor plate were bolted to this plate by means of studs through the bottom surface of the plate. Pins were inserted through these blocks and the wing hinge and lock fittings so that the method of attachment was similar to that of the actual aircraft. A smaller bolt served to secure the wing near the trailing edge.

Damage to Aircraft by Blast

Considerable trouble was experienced on successive detonations, as higher than expected blast pressures were needed to damage the wing, in maintaining the rigidity and integrity of the attachment fittings. The clamping arrangement shown in Figure 19 was found to be weak even with the addition of another clamp on the opposite side of the rail in front of the main spar. Bolts of higher tensile strength were substituted for those which stretched, but these stretched also. Finally, it became necessary to clamp down the entire forward and backward edge of the 1 inch armor plate by means of additional 7/8" plates with 8 additional bolts per side. It was also necessary to increase the strength of the fittings holding the wing to the 1 inch armor plate. The stud bolts holding the attachment blocks were increased from 3/4" to 1", with a coarser thread, and 3 blocks used on the lower fitting facing the blast. For the last detonations a total of six stud bolts were used to hold the attachment fittings to the plate on the side facing the blast. At no time did the wing break completely away from its attachments, however, and damage to it was attributable entirely to the blast.

The "harp" background used for showing the blast wave approaching the under surface of the wing was made of angle iron and 1/2" steel rod. The two legs of the right triangle thus formed were each 10 feet long. The contrast between the rods and the background was found to be insufficient, so 1" x 3" boards were fastened to the rods and painted one half white and one half black. The "harp" for the majority of detonations was placed between the wing and the gas stand and on the opposite side of the wing from the cameras. The "harp" was omitted on final shots as it was felt that it contributed little to the recorded data.

The under surface of the wing itself was painted in a line grid so as to show deformations more readily. The pattern of the markings is shown in Figures 18 and 19. The wide black lines on the surface of the wing are positioned over the internal supporting structure of the wing, as indicated by lines of rivets. About half of the vertical lines are also over supporting structure with each of the remaining lines through the center of each area of unsupported skin. The horizontal lines between the wide lines simply divide the area into equal sections.

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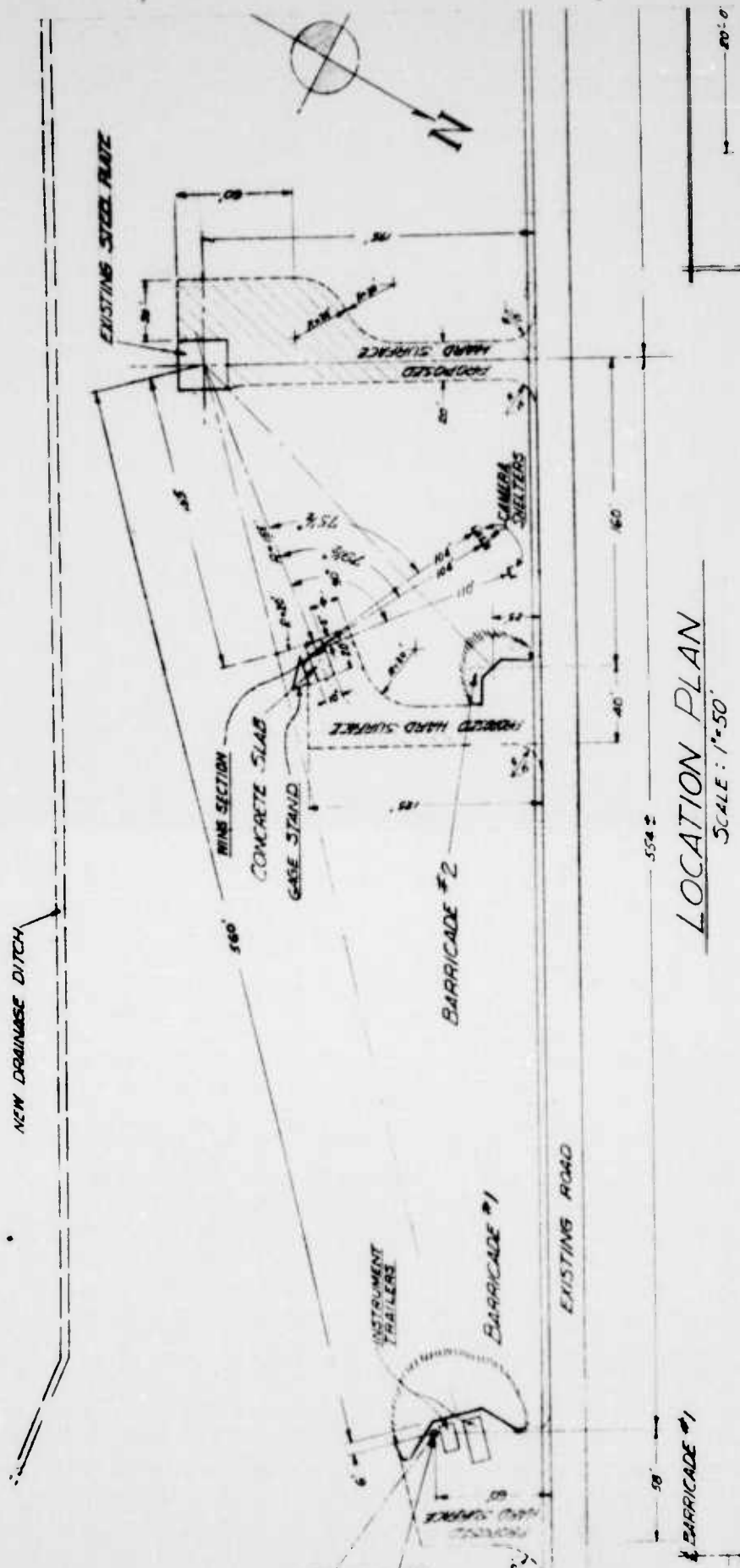


Figure 16

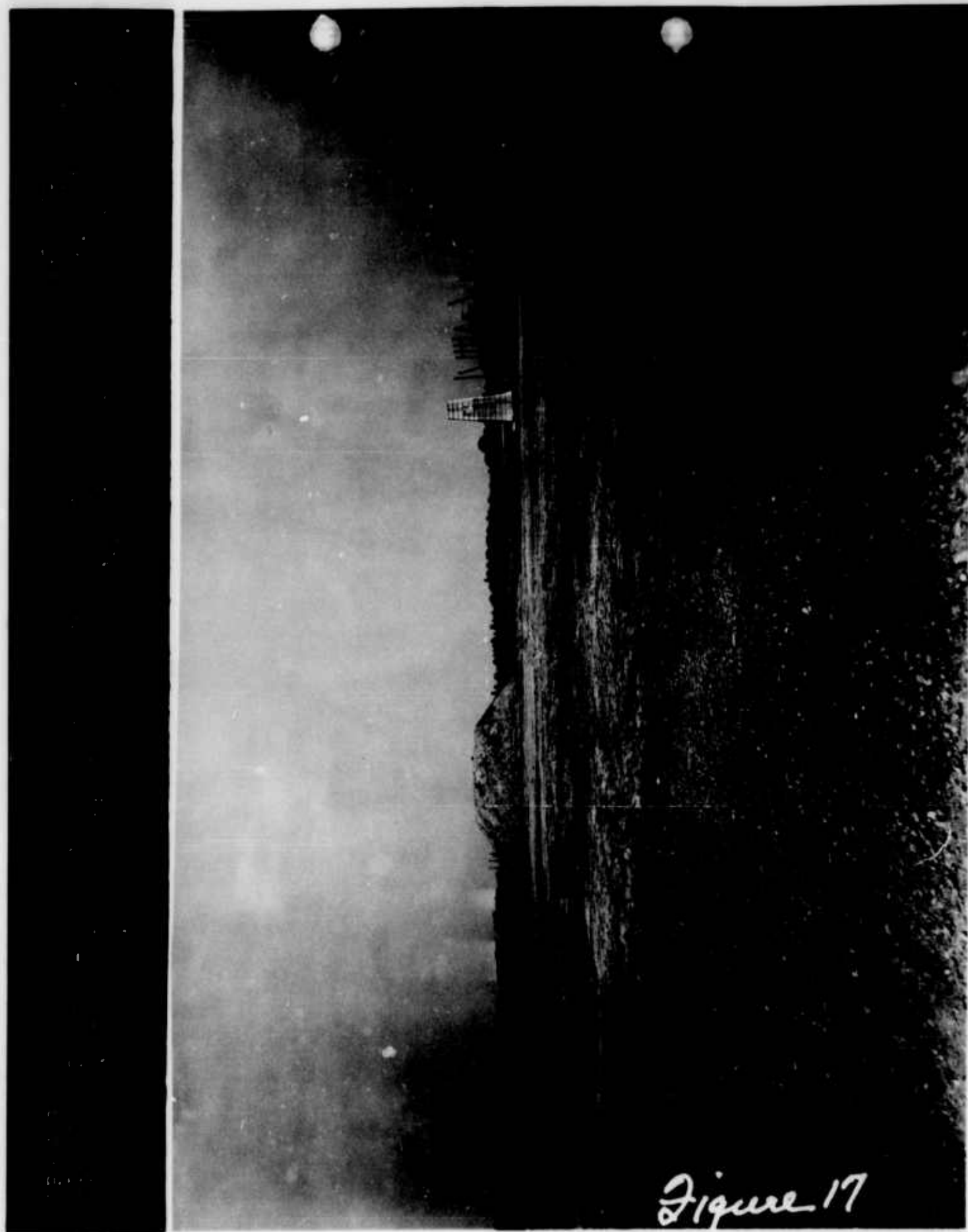


Figure 17

NP9 49327

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SECURITY INFORMATION
MIT Blast Program - P9F right hand outer wing panel mounted on a concrete slab with gage stand and set-up for broken-wire photography.



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NP9 49328

MIT Blast Program - F9F right hand outer wing panel mounted on rails imbedded in a concrete slab. The wing attachment fittings are held to the 1" armor plate by steel pins.

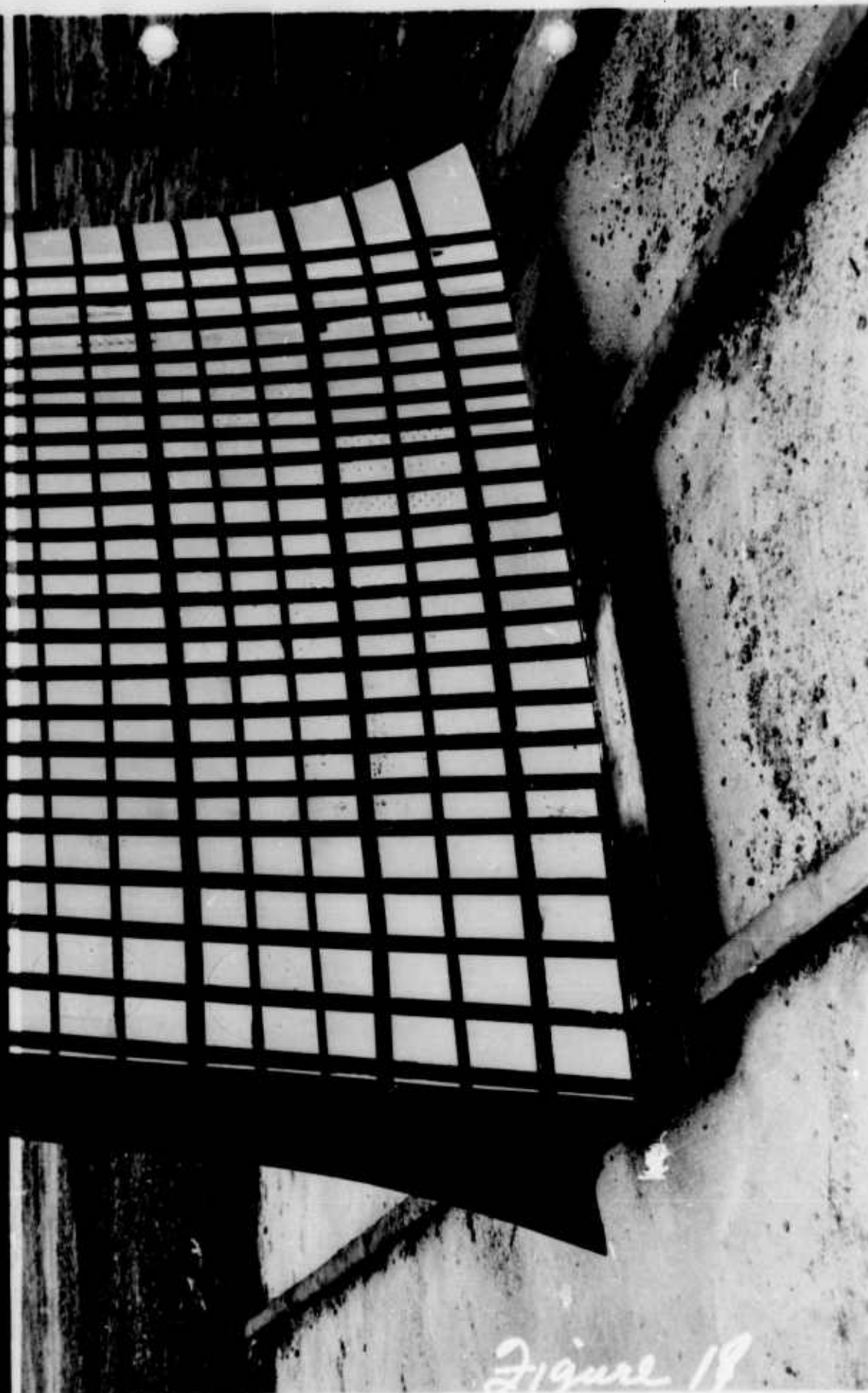
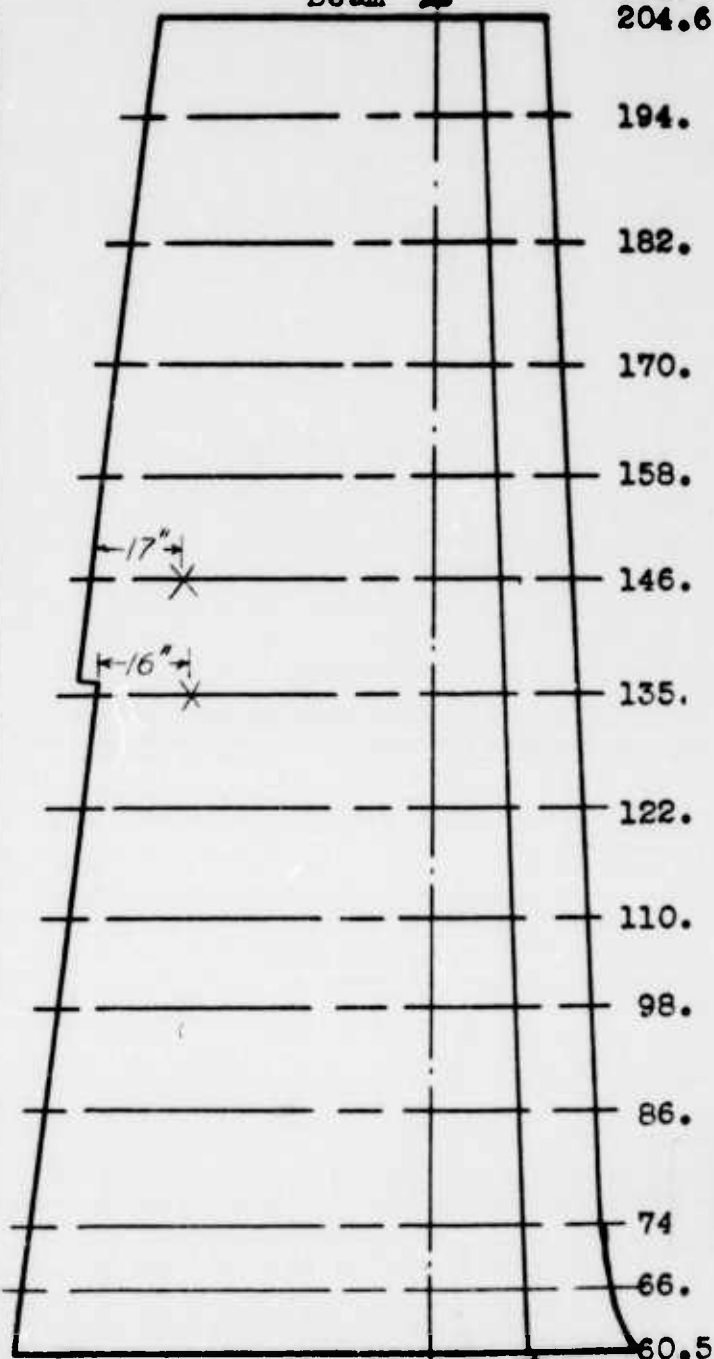


Figure 18

Sta.
204.6

Rib capstrip angles - upper and lower - and the rib web at sta. #135, 16" inboard of the wing trailing edge were wrinkled. One (1) spanwise "Z" stringer on the upper surface, 15" inboard of the trailing edge at sta. #136 was buckled. Three (3) rivets on the upper capstrip angle were loosened. The rib capstrip angles - upper and lower - and the rib web at sta. #146, 17" inboard of the trailing edge, also wrinkled.

X - Denotes internal damage



Movable & Leading
Edge Hinge Point.

RIGHT WING OUTER PANEL, UNDERSIDE.
MODEL F9F-4

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SECURITY INFORMATION

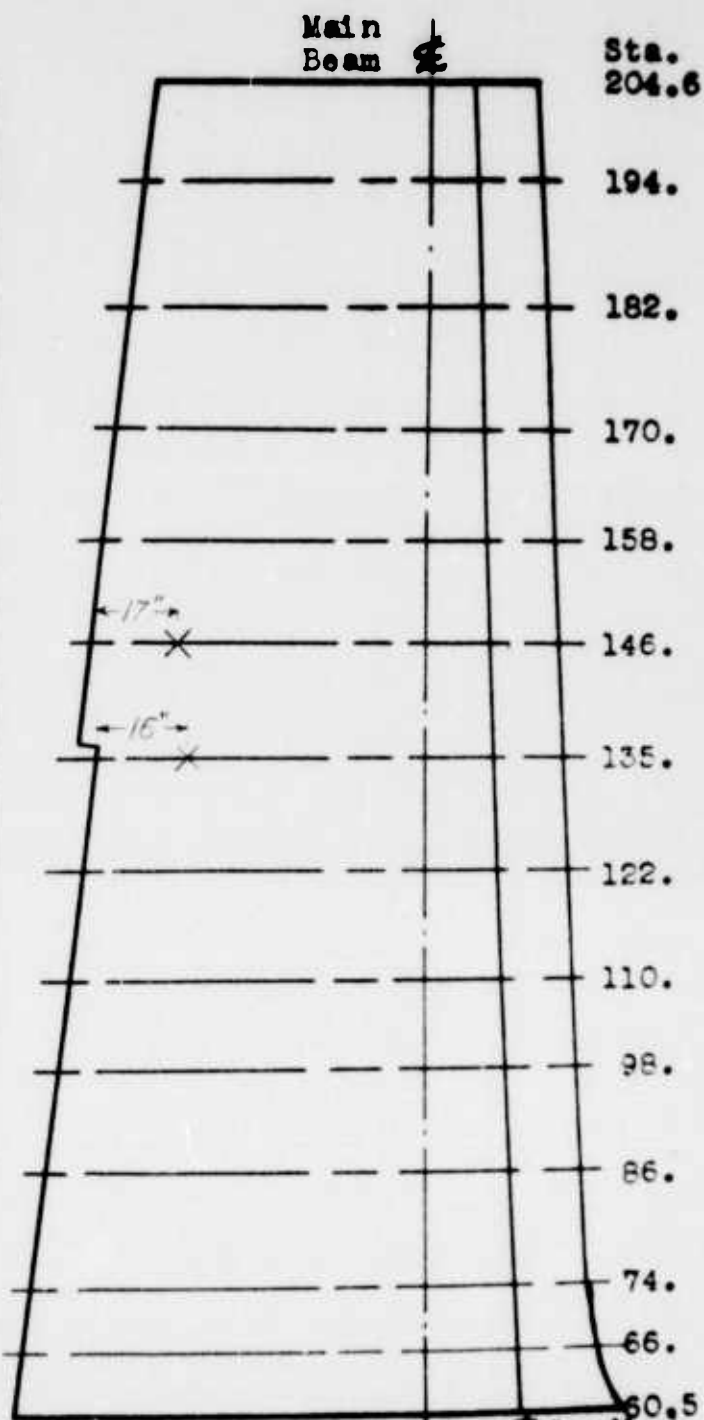
NP9 49450

NP9 49450
Damage to Aircraft by Blast. Data on Nature and Extent of Blast Damage.
Detonation No. 19, 450 lbs. of TNT at 76 feet.

Figure 20

[illegible]

RIGHT WING OUTER
MODEL



RIGHT WING OUTER PANEL, UNDERSIDE.
MODEL F9F-4

NP9 49451 19 June 1952
Damage to Aircraft by Blast. Data on Nature and Extent of Blast Damage.
Detonation No. 20, 500 lbs. of TNT at 76 feet.

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SECURITY INFORMATION

Damage to Aircraft by Blast. Data on Nature and Extent of Blast Damage.
Detonation No. 20, 500 lbs. of TNT at 76 feet.

Figure 21

Remarks: Det. #22 - 500# TNT - 73 1/2'

Moveable leading edge's lower surface dished-in, damage extending from sta. #98.5 to #146. Maximum depth was 3/16" at sta. #122. Minimum depth was 1/8" at sta. #144.

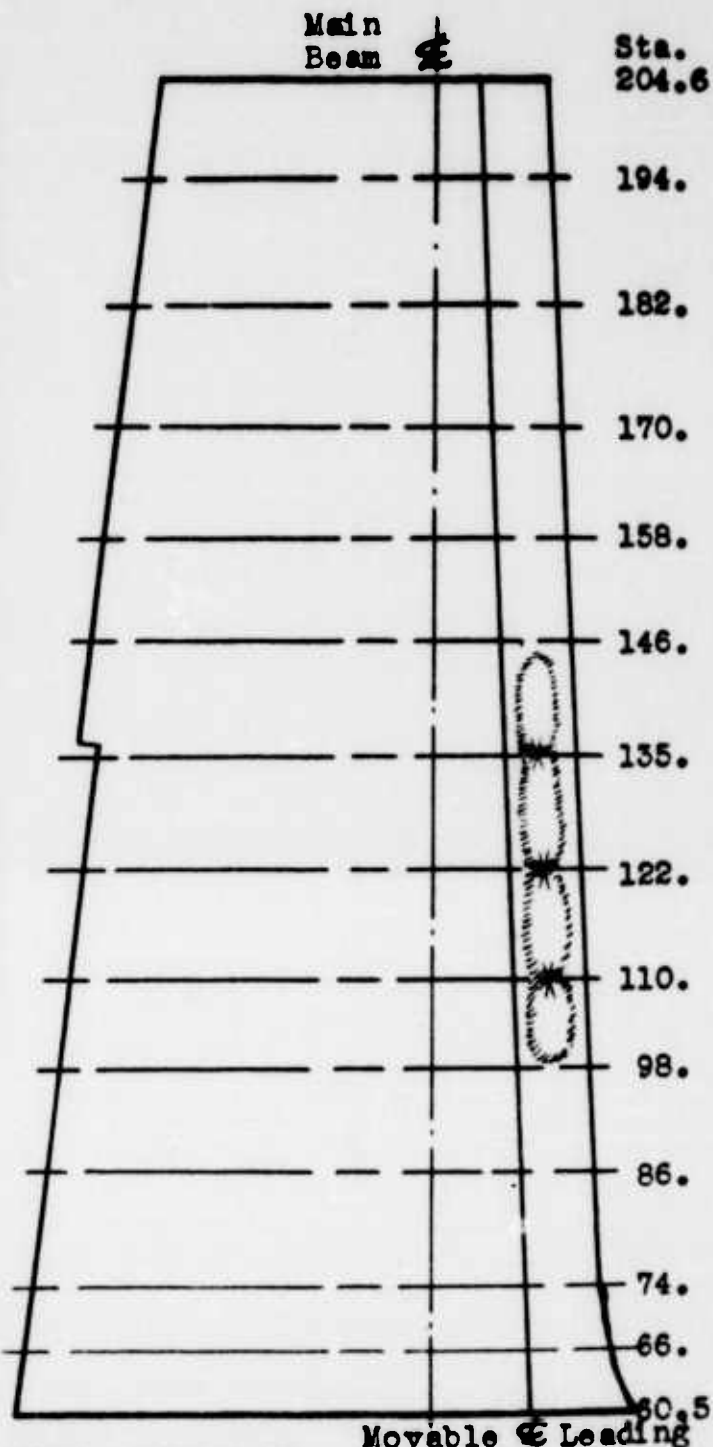
Tear in rib webs - extending from lightening hole flange through the rib capstrip - occurred at sta. #109, #121, and #136 on moveable leading edge. Span-wise "Z" stringer on lower leading edge surface cracked at points of contact with ribs (sta. #109, #121 and #136).

Six (6) flush rivets on lower surface of leading edge loosened at sta. #109, five (5) rivets loosened at sta. #121, and three (3) loosened at sta. #136. These rivets ran chordwise, attaching rib cap-strip angle to skin.

Shaded area indicates dishing-in
X - Denotes internal damage

Shaded area indicates dishing-in

X - Denotes internal damage



Movable & Leading
Edge Hinge Point.

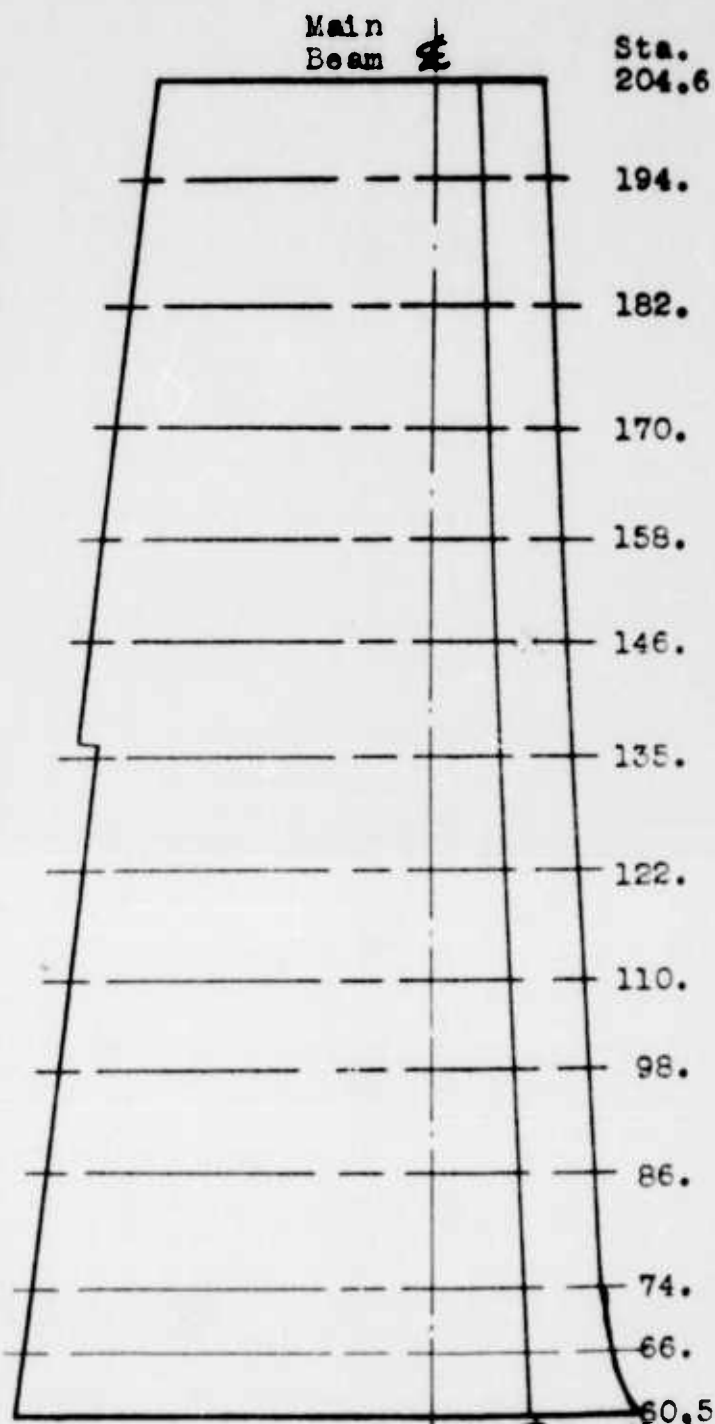
RIGHT WING OUTER PANEL, UNDERSIDE.
MODEL F9F-4

NP9 49452 19 June 1952 CONFIDENTIAL
Damage to Aircraft by Blast. Data on Nature and Extent of Blast Damage.
Detonation No. 22, 500 lbs. of TNT at 73.5 feet. SECURITY INFORMATION

19 June 1952

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SECURITY INFORMATION

Figure 22

[illegible]

RIGHT WING OUTER PANEL, UNDERSIDE.
MODEL F9F-4

Movable & Leading
Edge Hinge Point.

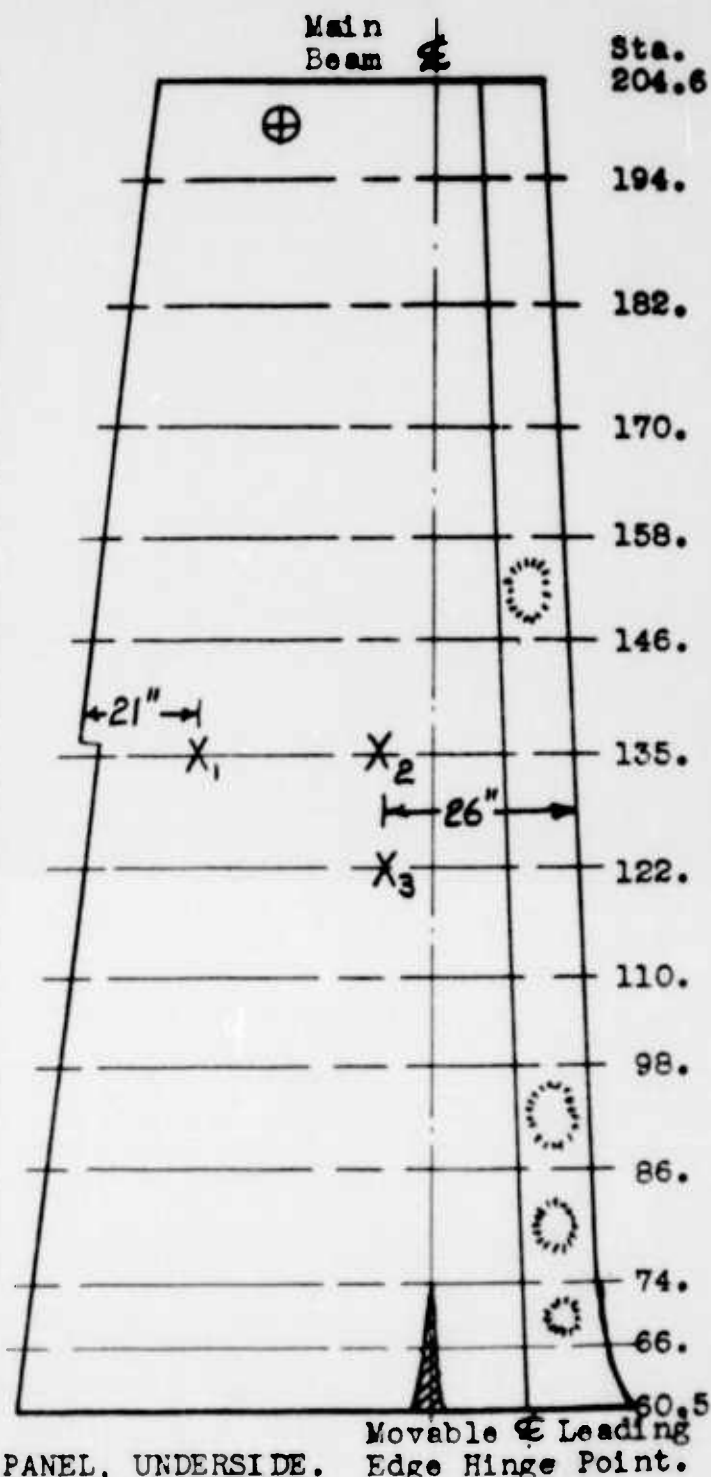
NP9 49453 19 June 1952 CONFIDENTIAL
Damage to Aircraft by Blast. Data on Nature and Extent of Blast Damage.
Detonation No. 23, 450 lbs. of TNT at 70 feet. SECURITY INFORMATION

19 June 1952

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SECURITY INFORMATION

Figure 23

Remarks: Det.#24 - 450#TNT - 70'	
⊕	- Minor pulling of formation light retainer ring between screws, approximately 1/32".
⊙	- Shaded areas indicate a very slight dishing-in of skin.
X ₁	- Aileron push-pull rod was pinched slightly by vibrating fore and aft against webbing of chord.
X ₂	- Wing-tip-tank fuel line was pinched slightly by vibrating fore and aft against webbing of chord.
X ₃	- Hold-down strap for above fuel line indicates minor pulling at this point.
▨	- Cross-hatched area at base of wing indicates minor curling-in of skin along hinged side of the movable leading edge.



RIGHT WING OUTER PANEL, UNDERSIDE.
MODEL F9F-4

NP9 - 50861

10 June 1952

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SECURITY INFORMATION

DAMAGE TO AIRCRAFT BY BLAST - Data on Nature and Extent of Blast Damage.
Detonation No. 24, 450 lbs of TNT at 70 feet.
Figure 24

Figure 25

5 - Arrows indicated sheared rivets in chordwise gussets across trailing edge.

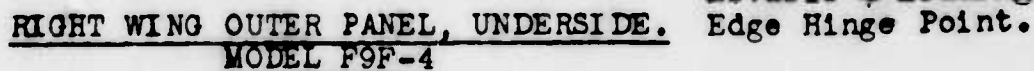
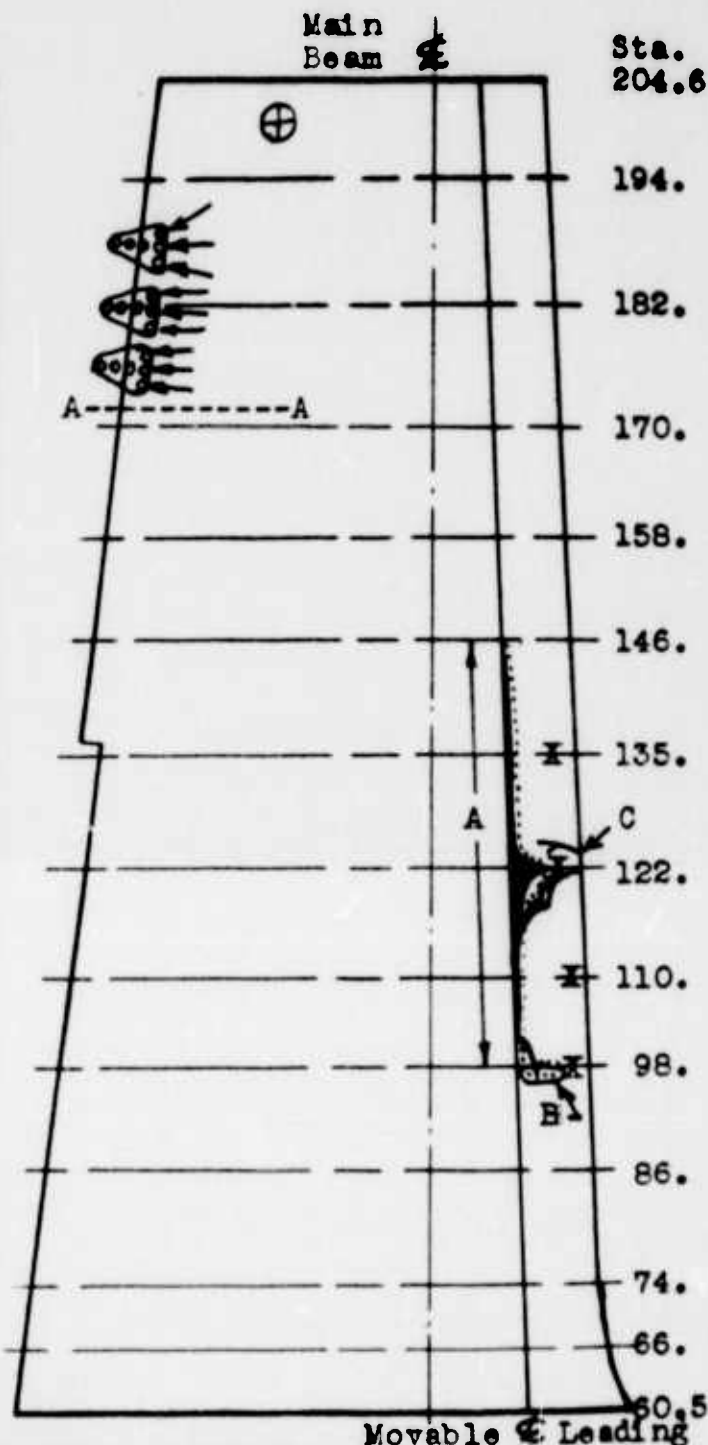


Figure 2.6

Remarks: Det. #27 - 500#TNT - 67'
⊕ - Minor additional pulling of formation light.
↔ - Arrows indicate sheared rivets in chordwise gussets across trailing edge.
A-----A - Skin tear on upper surface; extending from the piano-hinge break (occured on Det. #26) in toward center of wing for a distance of approx. 18".
I - Rib webs shattering about previous cracked areas.
A - On upper surface, or back side of wing, skin opened along spanwise row of rivets near rear of movable leading edge, between Sta. #98.0 and #146.0
B - Sta. #98.0 - 14 chordwise rivets sheared on movable leading edge.
C - Sta. #123.0 - Crack in skin around leading edge.



RIGHT WING OUTER PANEL, UNDERSIDE.
MODEL F9F-4

Movable Leading
Edge Hinge Point.

NP9 - 50864

20 June 1952

CONFIDENTIAL
SECURITY INFORMATION

DAMAGE TO AIRCRAFT BY BLAST - Data on Nature and Extent of Blast Damage.
Detonation No. 27, 500 lbs of TNT at 67 feet.

Figure 27

Sta.
204.6

Main
Beam

194.

182.

170.

158.

146.

135.

122.

110.

98.

86.

74.

66.

60.5

Movable Leading
Edge Hinge Point

LEFT WING OUTER PANEL, UNDERSIDE.
MODEL P9F-4

NP9 - 50865

26 June 1952

CONFIDENTIAL
SECURITY INFORMATION

DAMAGE TO AIRCRAFT BY BLAST - Data on Nature and Extent of Blast Damage.
Detonation No. 28, 500 lbs of TNT at 70 feet.

Figure 28

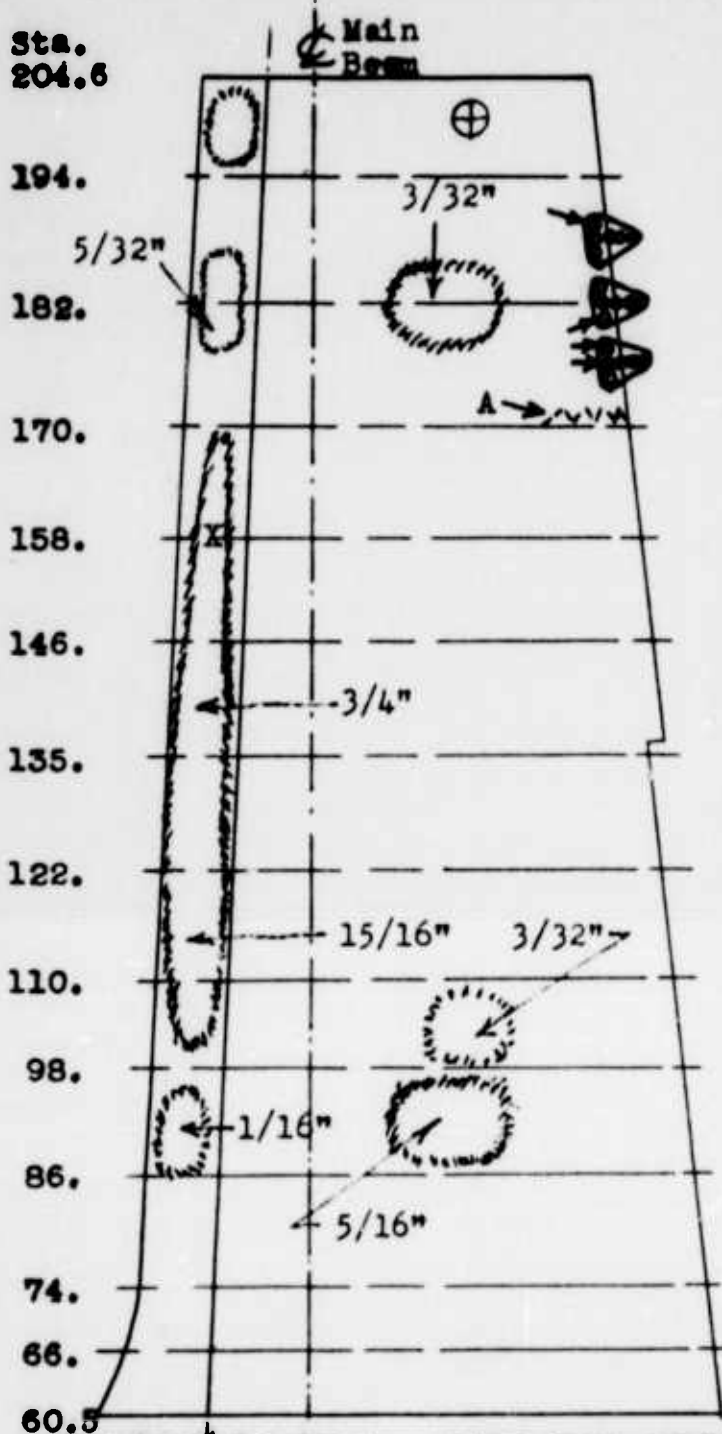
Remarks: Det.#28 - 500#TNT - 70'

⊕ - Formation light retaining
ring pulled approx. 1/16" between
screws.

X - Rib webbing cracked from
spanwise stringer recess to light-
ening hole.

⊙ - Shaded areas indicate dished-
in skin. Numerical values are the
maximum depths.

Sta.
204.6



Movable Leading
Edge Hinge Point

LEFT WING OUTER PANEL, UNDERSIDE.
MODEL F9F-4

Remarks: Det.#30 - 500#TNT - 64'

⊕ - Additional pulling of formation light. Retaining ring pulled away from (3) screws.

↖ - Arrows on sheet-metal gussets across trailing edge indicate sheared rivets.

A - On back side, upper surface, 6" skin break appeared as piano-hinge and supporting spanwise angle sheared at Sta.#171.0

X - Sta.#158.0, Rib web cracked from lightening hole to spanwise stringer.

⊙ - Shaded areas indicate skin dish-in. Numerical values are Max. depth in inches.

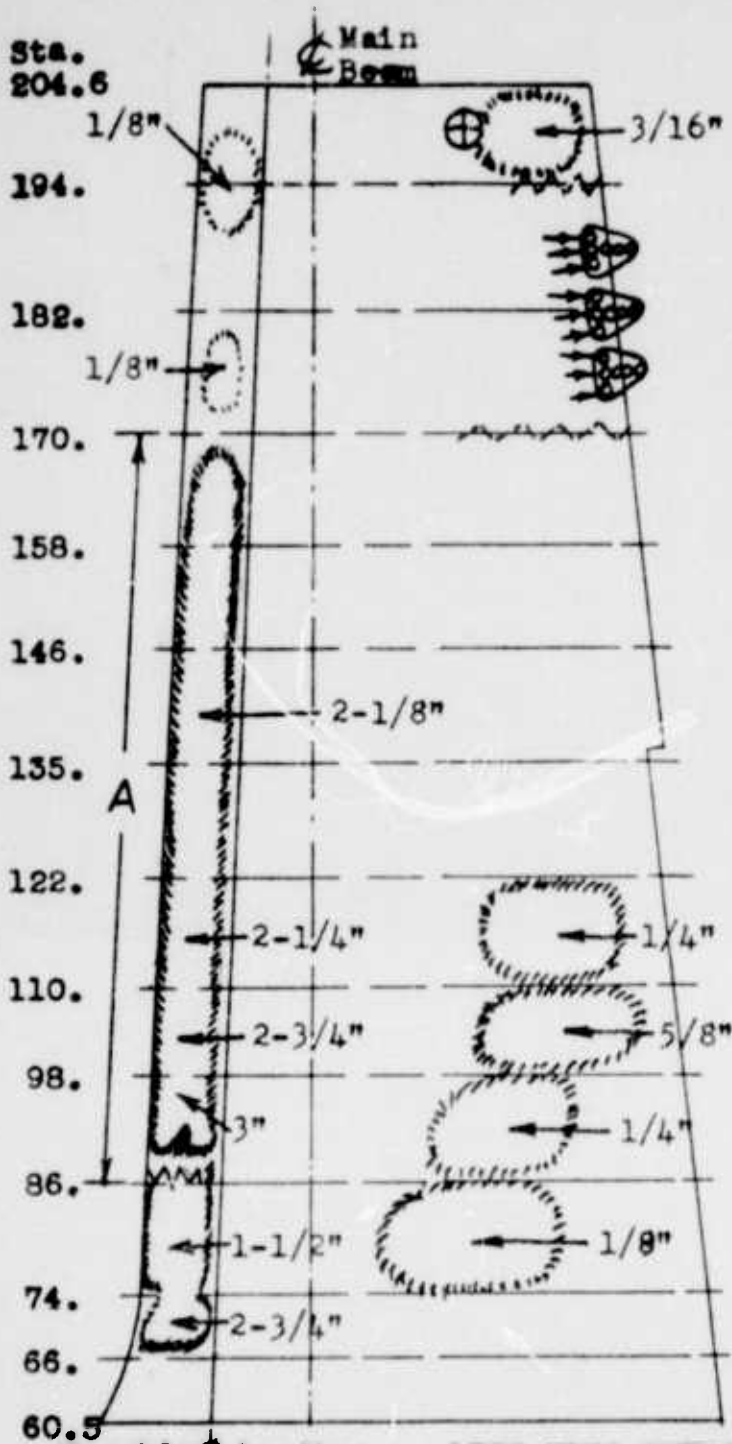
NP9 - 50867

27 June 1952

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SECURITY INFORMATION

DAMAGE TO AIRCRAFT BY BLAST - Data on Nature and Extent of Blast Damage.
Detonation No. 30, 500 lbs of TNT at 64 feet.

Figure 30



Remarks: Det.#31 - 500#TNT - 61'

⊕ - Formation light pulled out.

⊕ - Remaining (arrows) rivets all sheered in gussets across trailing edge. Back side, upper surface, was forced back and away, causing indicated skin-tear at Sta.#170. and #194. See accompanying Photo, NP9-50785, Fig. 48.

A - Sta.#86.0 thru #170.0 - Movable leading edge dished-in and moved backward. See accompanying Photos, NP9-50783, Fig. 46; and NP9-50784, Fig. 47

⊕ - Shaded areas indicate skin-dish-in. Numerical values are Max. depths in inches.

Movable Leading Edge Hinge Point

LEFT WING OUTER PANEL, UNDERSIDE.
MODEL P9F-4

NP9 - 50868

1 July 1952

CONFIDENTIAL
SECURITY INFORMATION

DAMAGE TO AIRCRAFT BY BLAST - Data on Nature and Extent of Blast Damage.
Detonation No. 31, 500 lbs of TNT at 61 feet.

Figure 31

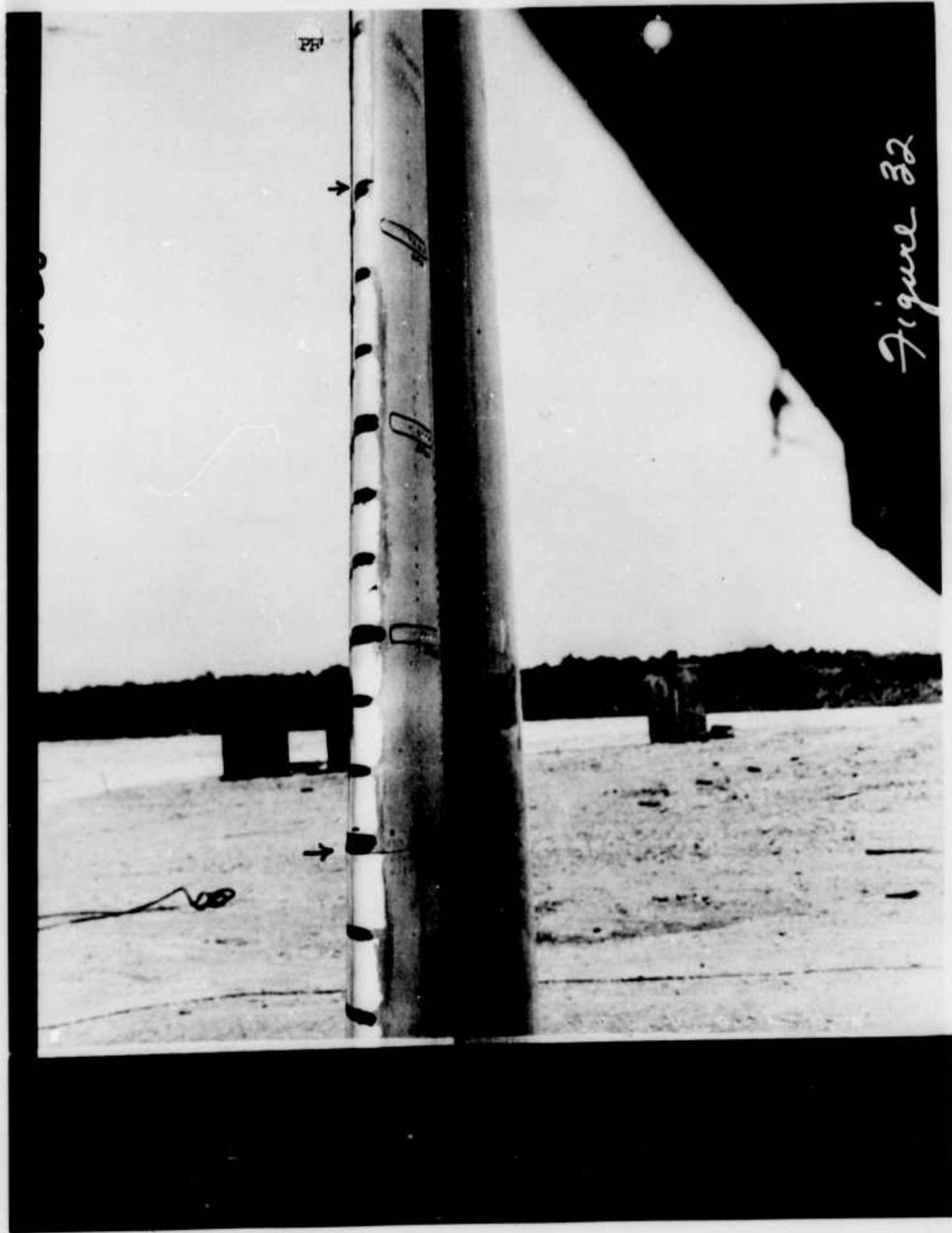


Figure 32



Figure 33

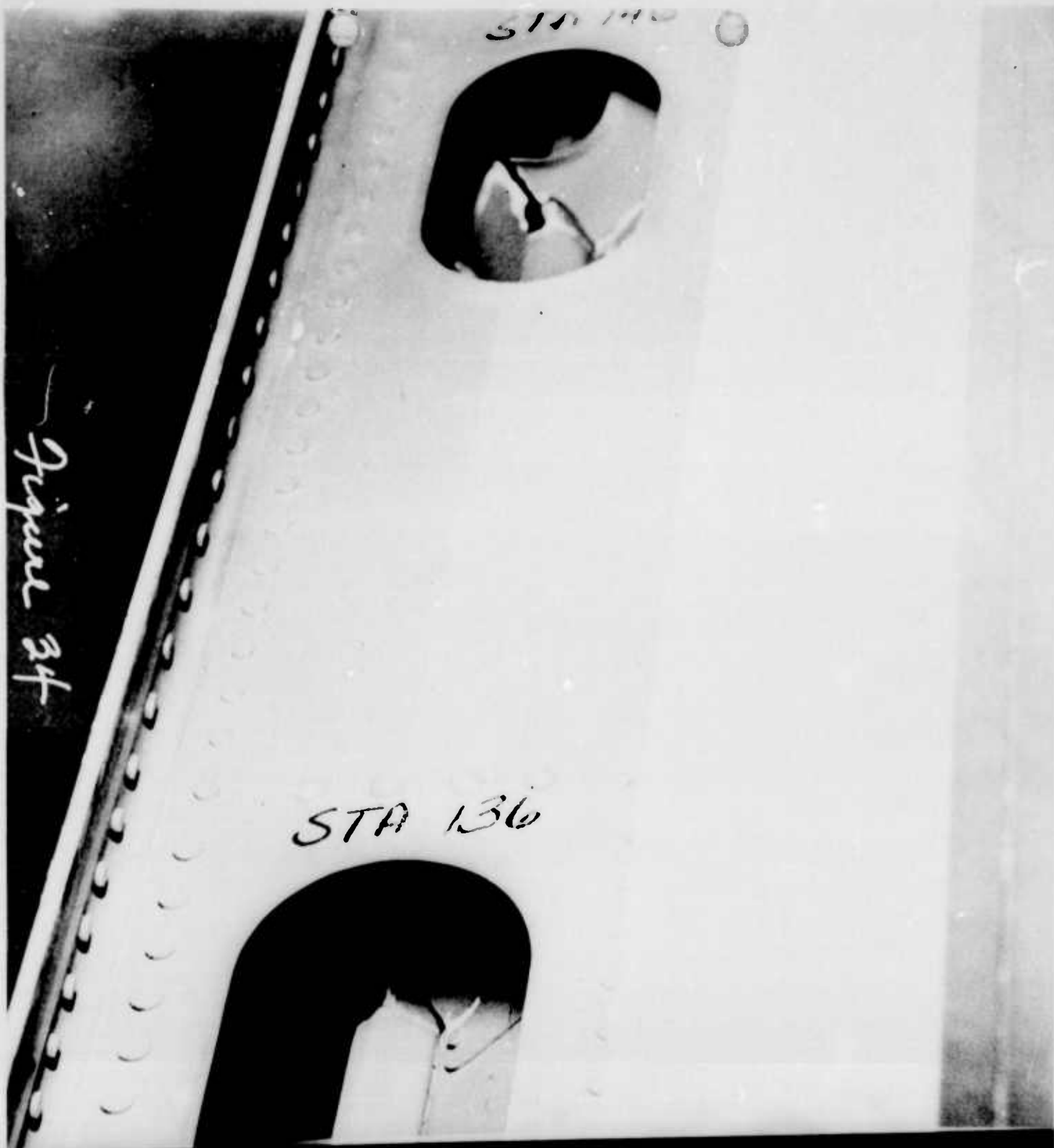


Figure 34. View of the interior of the structural member showing the rivet pattern and the internal openings.

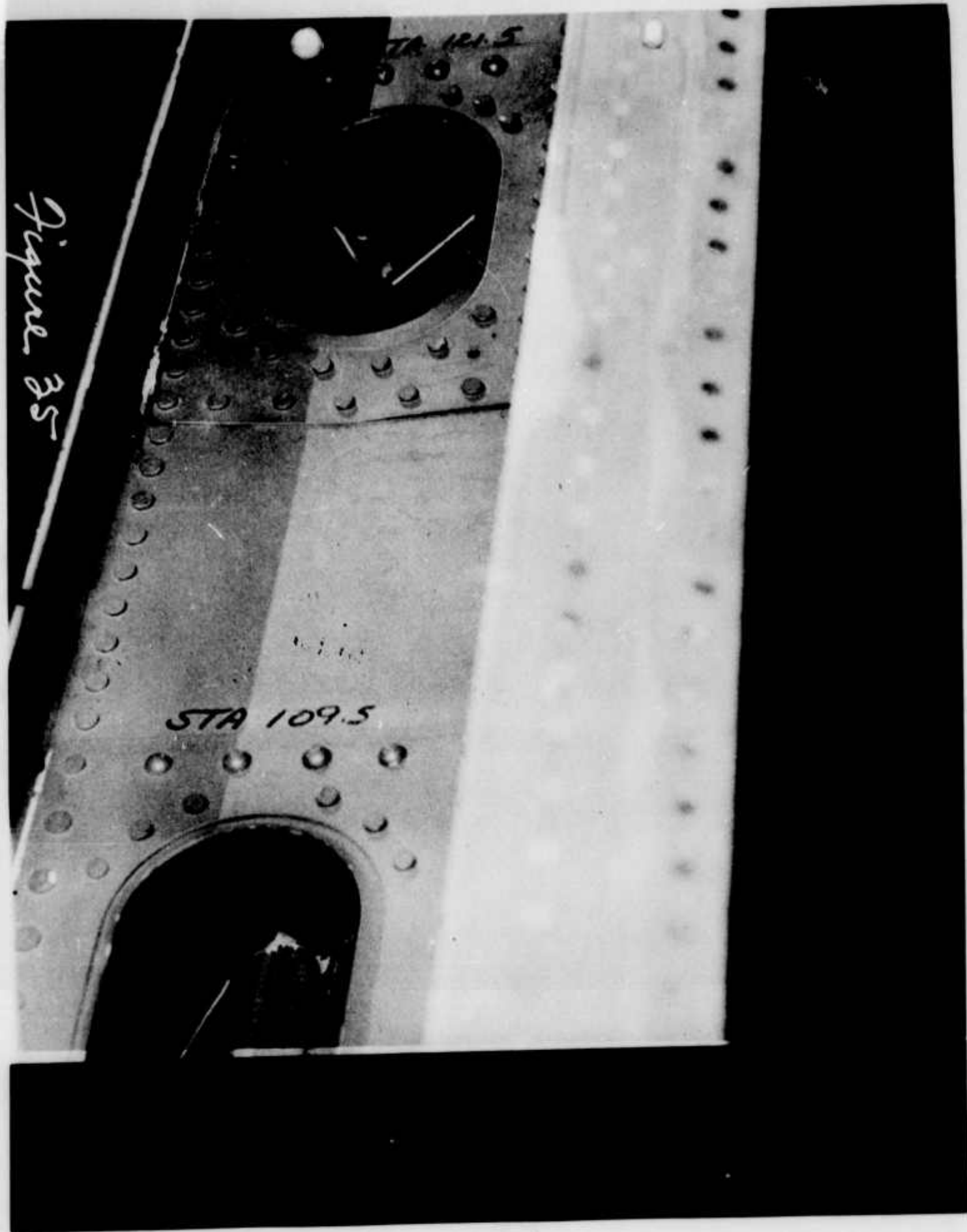
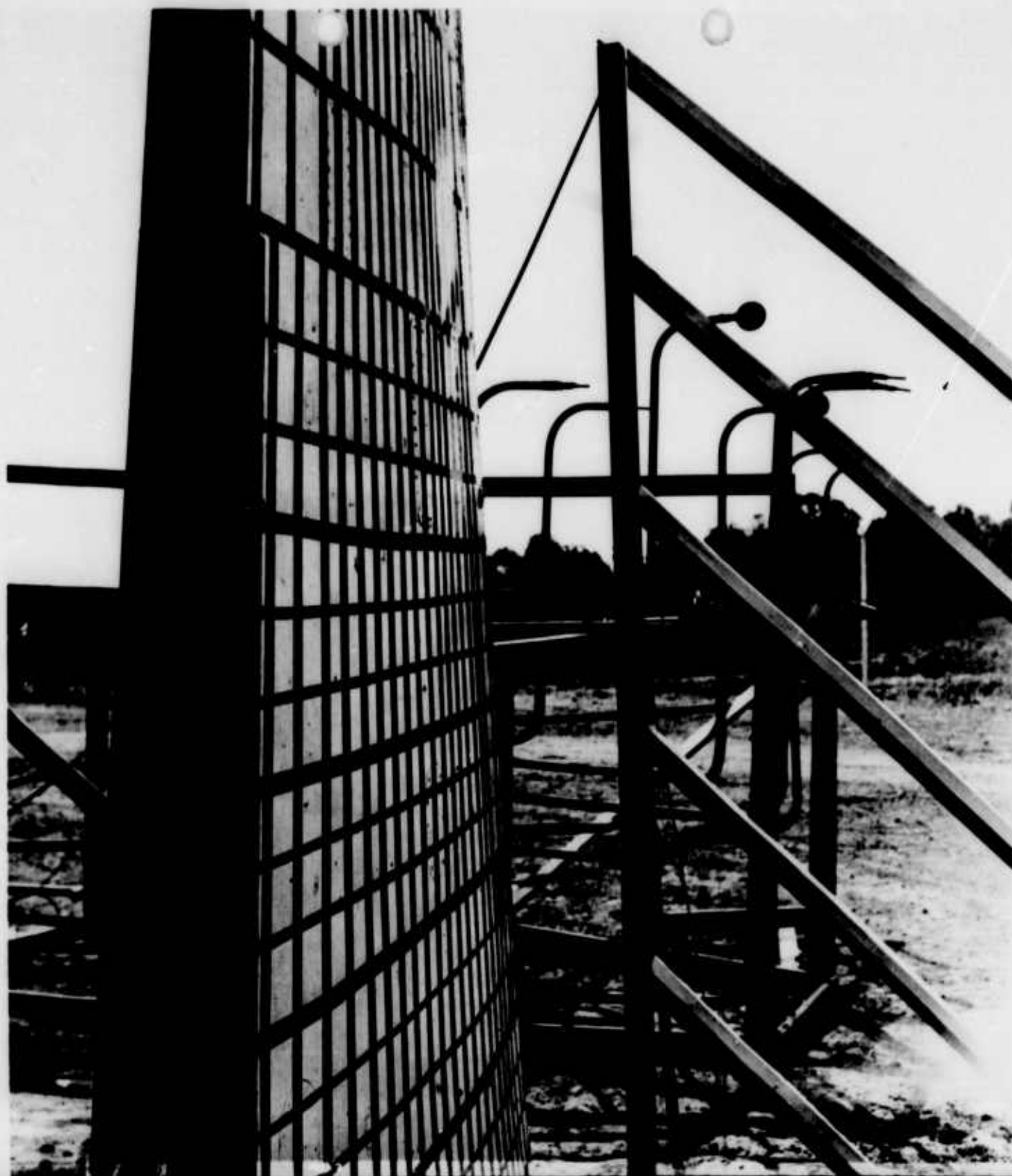


Figure 35



Figure 36



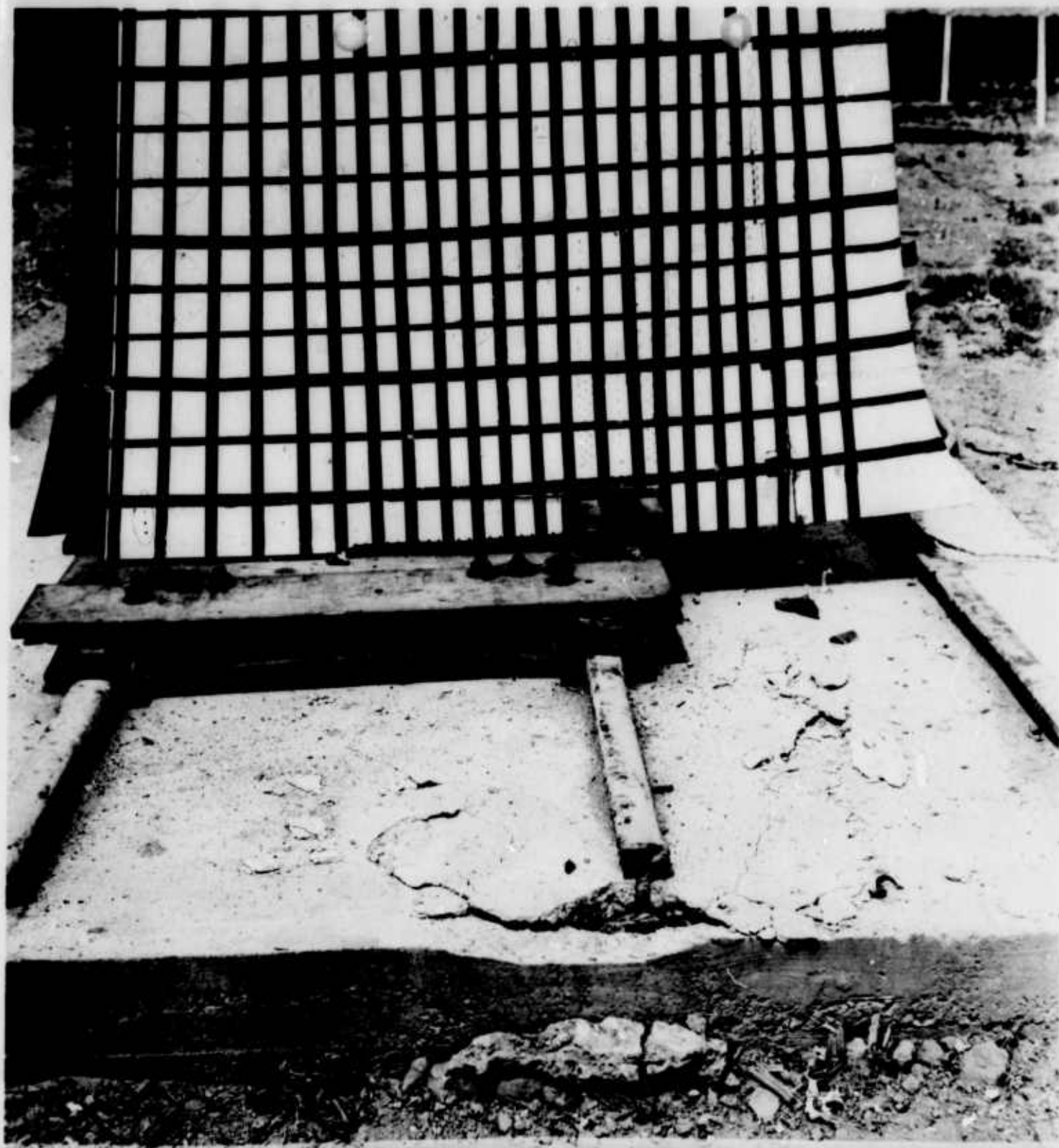
NP9-50774

10 June 1952

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SECURITY INFORMATION

Damage to Aircraft by Blast - A rear view of the under surface of model F9F-4, RH-Outer wing panel showing dishing-in of movable leading edge resulting from detonation #24.

Figure 37



NP9-50777

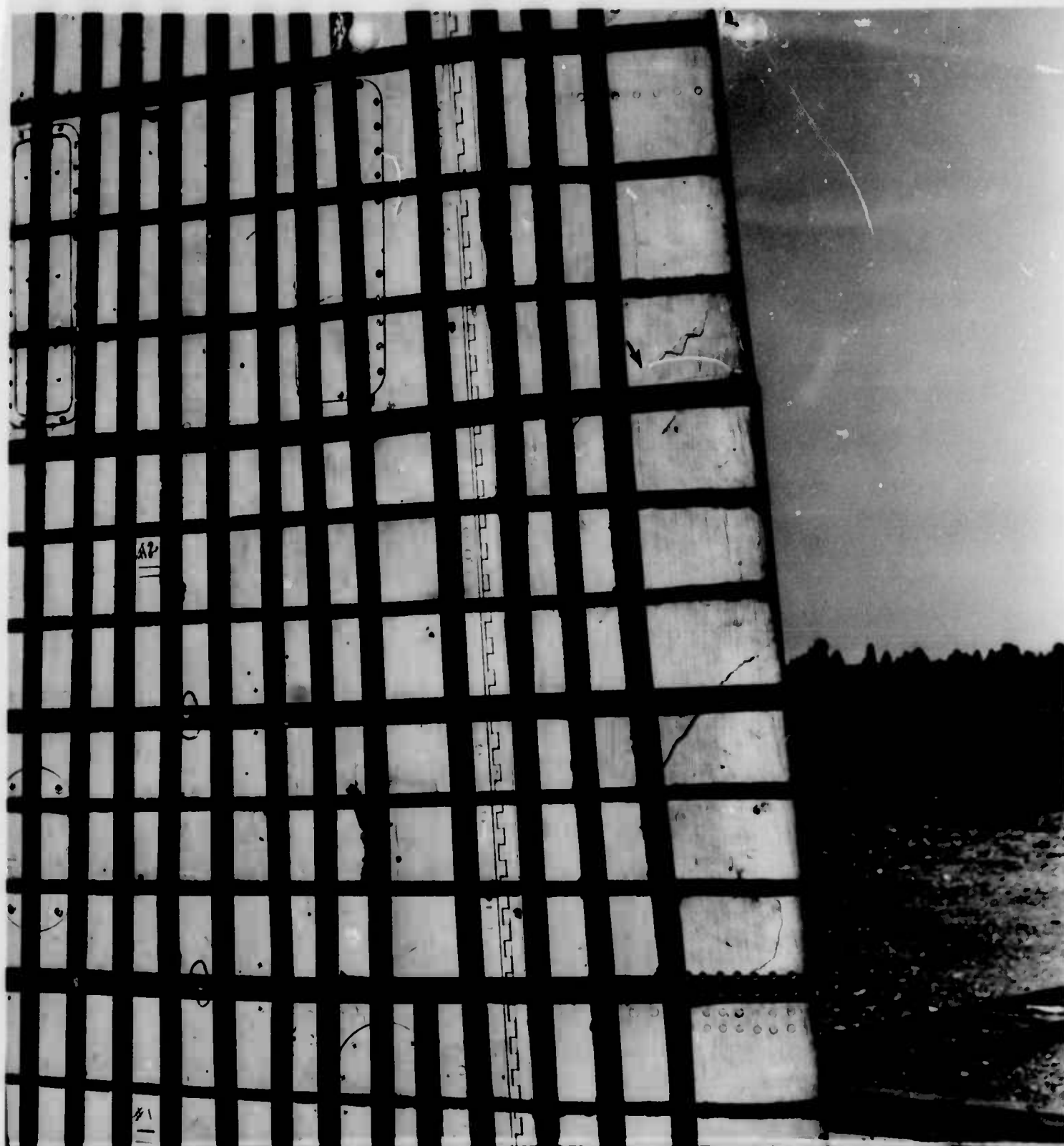
20 June 1952

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Damage to Aircraft by Blast - Front view of under side of model F9F-4, RH-Outer wing panel and mounting positioned on rails embedded in concrete slab, showing rail beneath main wing spar worked loose by detonation #27.

Figure 38



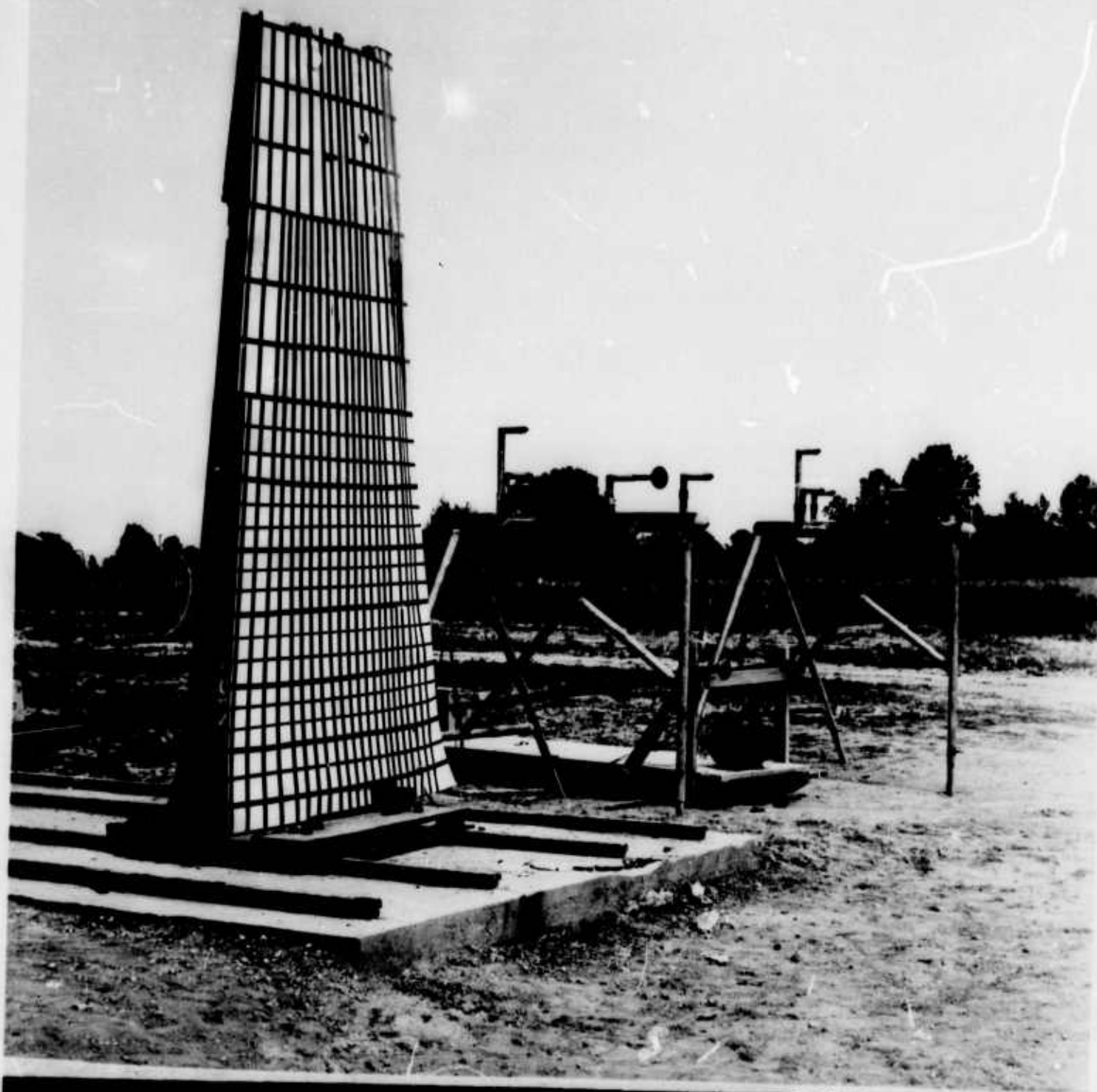
NP9-50778

20 June 1952

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Damage to Aircraft by Blast - Front view of under surface of model F9F-4, RH-Outer wing panel showing ruptured skin on movable leading edge resulting from detonation #27. Arrow indicates extent of skin tear. Note - 14 rivets gone at station #86.

Figure 39



NP9-50779

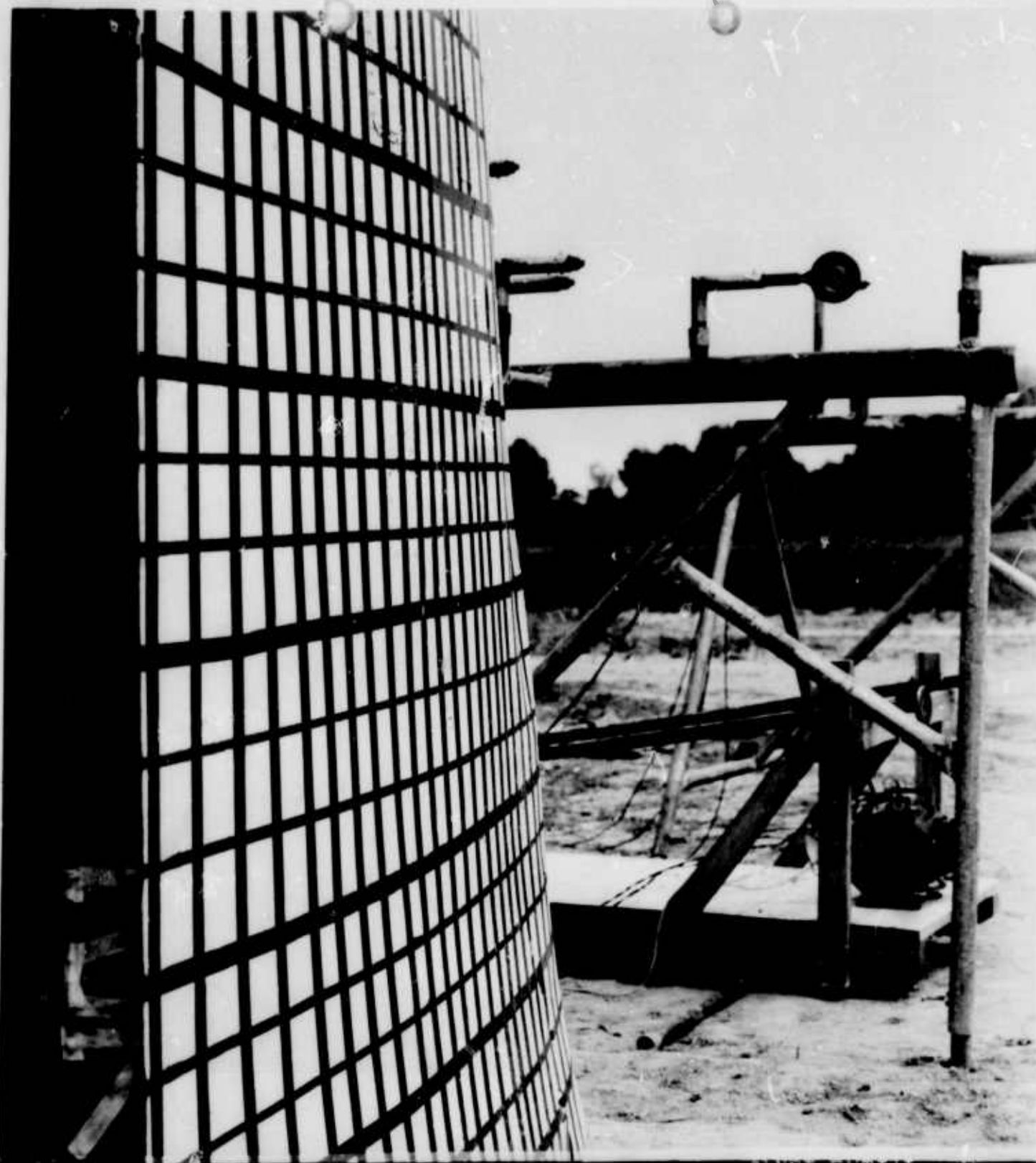
20 June 1952

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Damage to Aircraft by Blast - A three-quarter rear view of under surface of model F9F-4, RH-Outer wing panel, showing both "dished-in" movable leading edge, and damaged upper surface trailing edge resulting from detonations #26 and #27. Velocity and pressure gage results are shown alongside the wing. Face-on pressure gages and the Buck gage are between the two tripod stands.

Figure 40



NP9-50780

20 June 1952

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Damage to Aircraft by Blast - A rear chordwise view of model F9F-4, RH-Outer wing panel showing "dishing-in" of chords of the movable leading edge, resulting from detonations #26 and #27.

Figure 41



NP9-50776

20 June 1952

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Damage to Aircraft by Blast - A rear view of the upper surface of model F9F-4, RH-Outer wing panel showing damage to trailing edge and skin resulting from detonation #27. Note protruding movable leading edge.

Figure 42



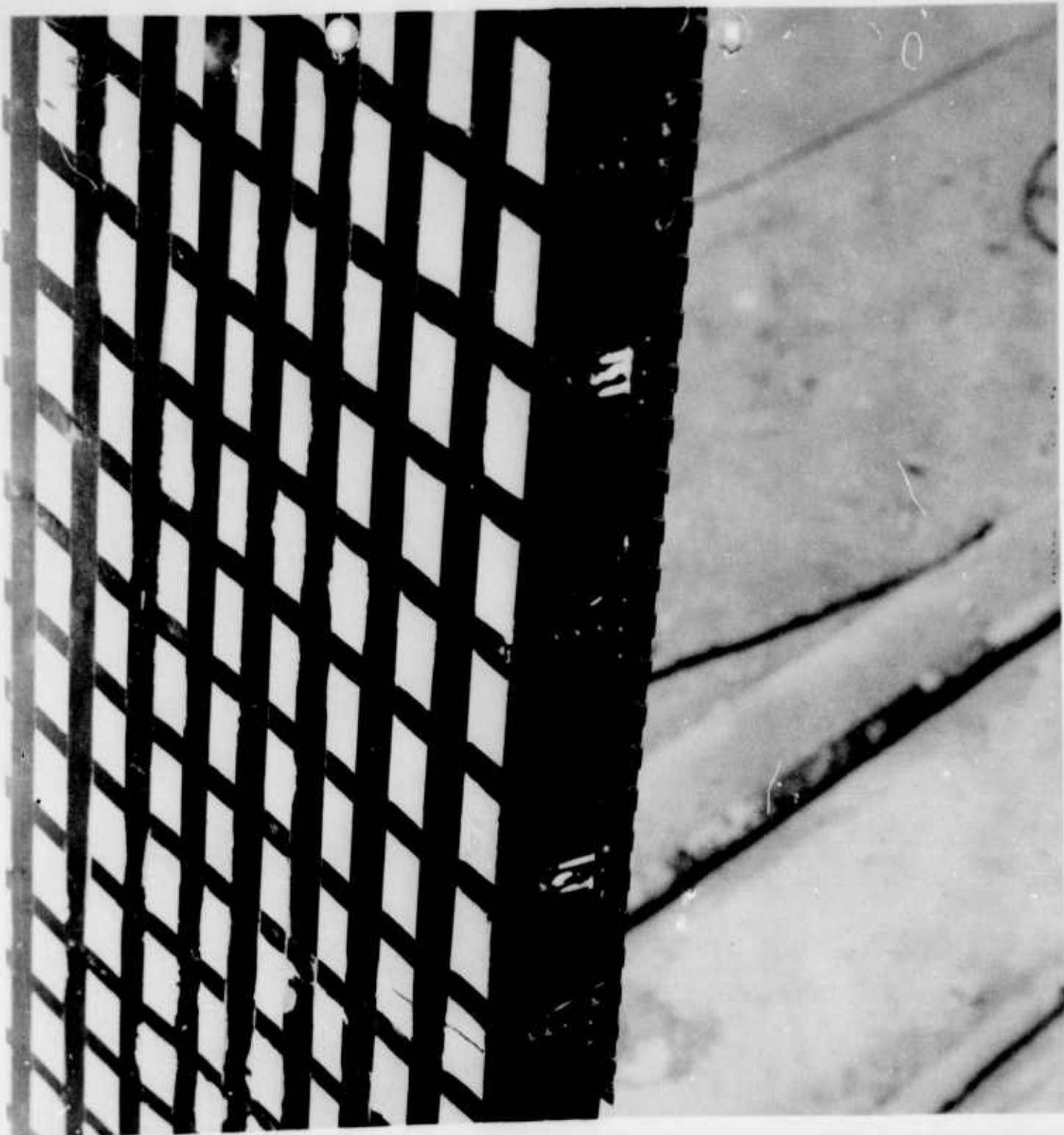
NP9-50775

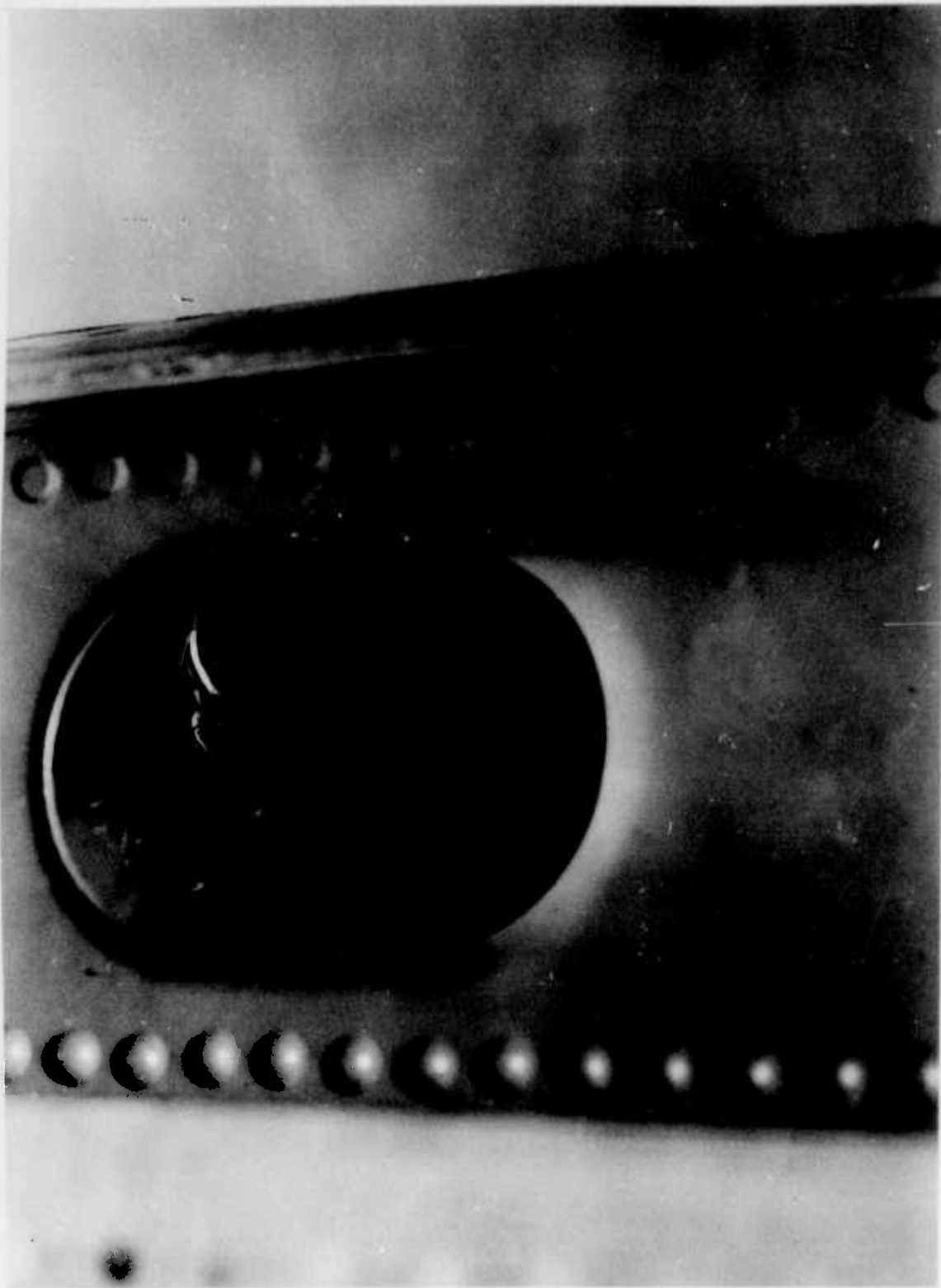
20 June 1952

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SECURITY INFORMATION

Damage to Aircraft by Blast - A rear view of upper surface of model F9F-4, mid-outer wing panel, showing ruptured chordwise ribs at stations #98, #110, and #122, and skin, resulting from detonations #22 (began to crack) thru #27.

Figure 43







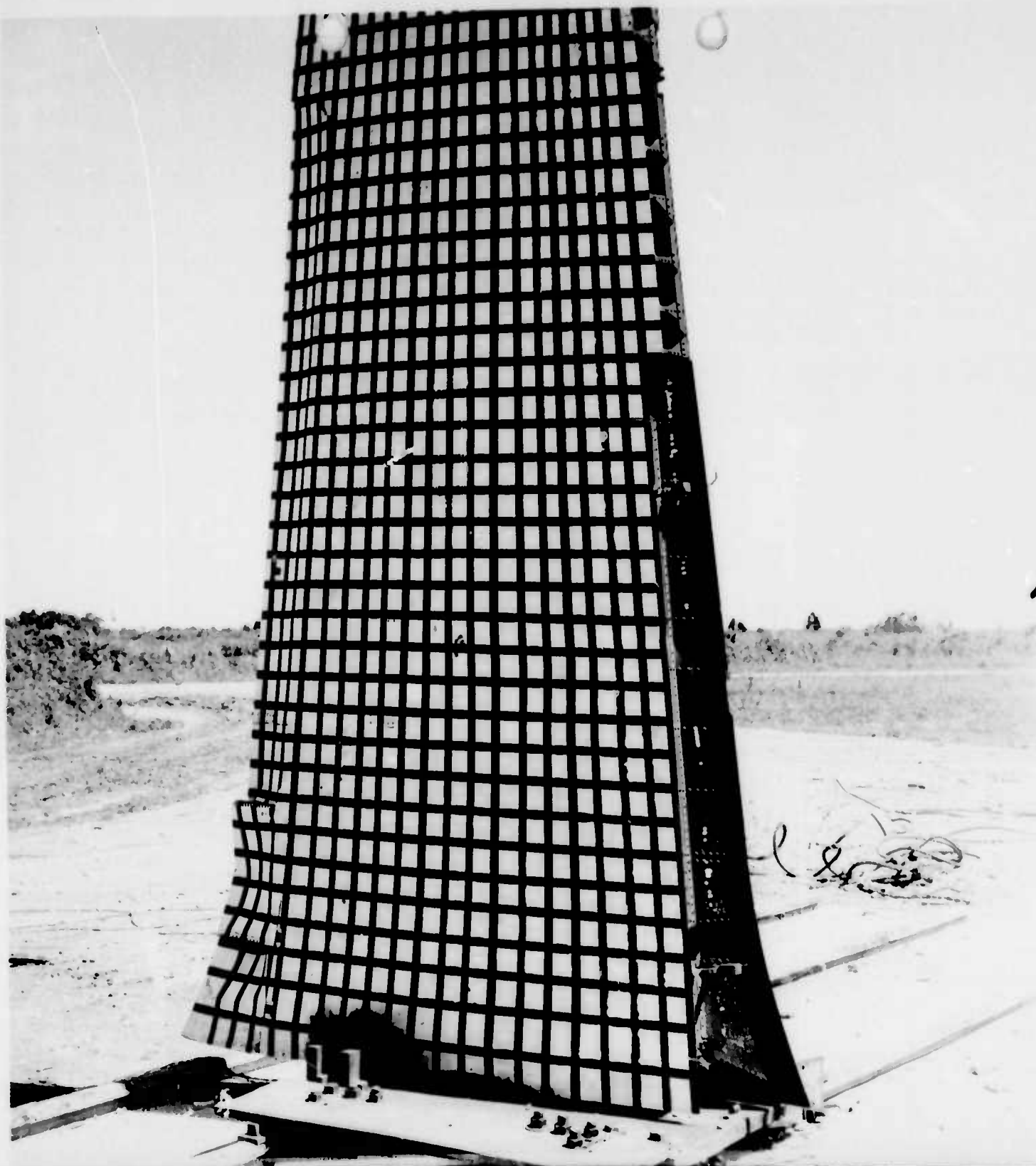
NP9-50783

1 July 1952

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SECURITY INFORMATION

Damage to Aircraft by Blast - A rear view of upper surface of model F9F-4, LH-Outer wing panel showing damaged movable leading edge resulting from detonations #30 and #31.

Figure 46



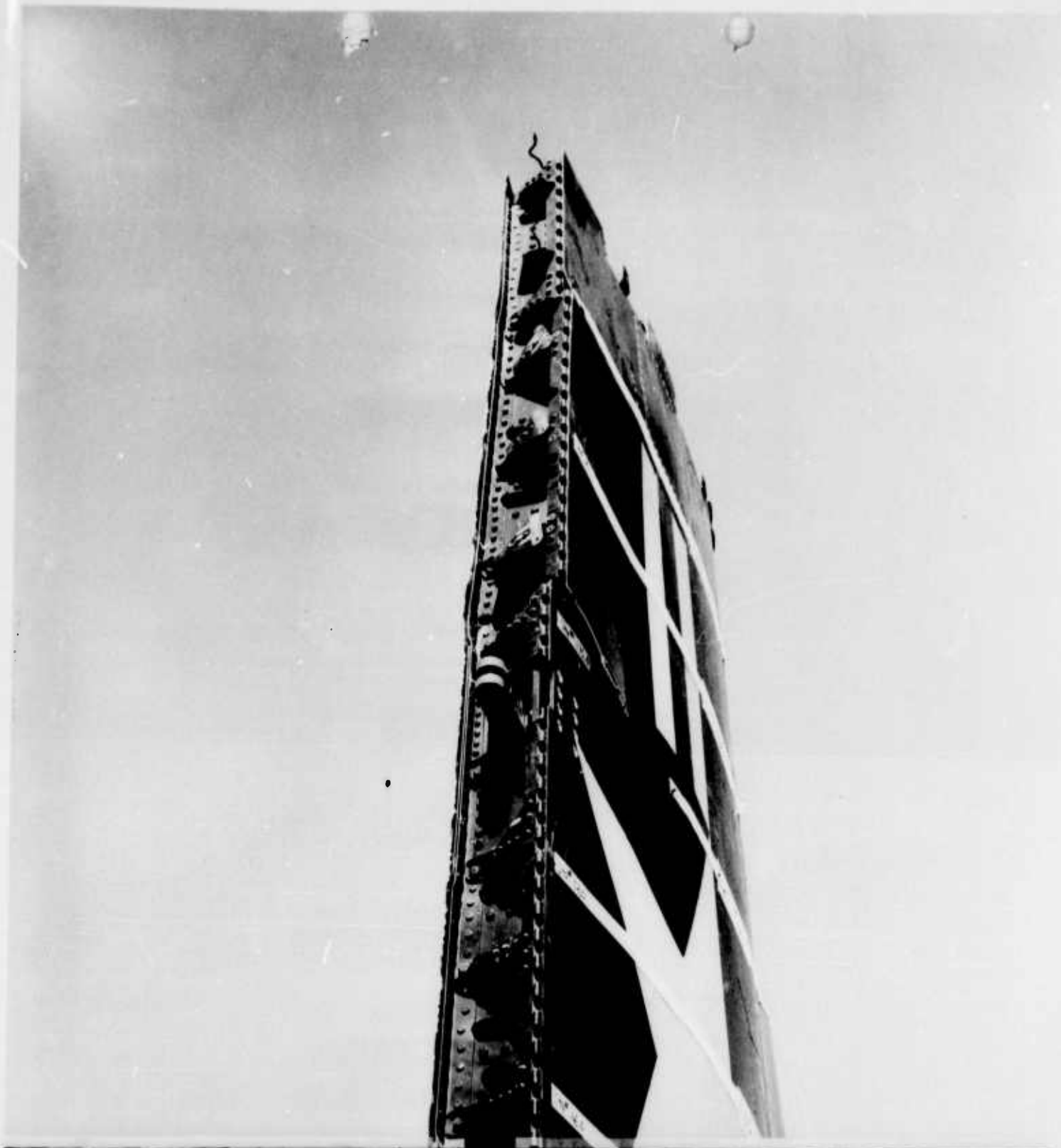
NP9-50784

1 July 1952

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Damage to Aircraft by Blast - View of under surface of model F9F-4,
LH-Outer wing panel showing ruptured movable leading edge resulting
from detonations #30 and #31.

Figure 47



NP9-50785

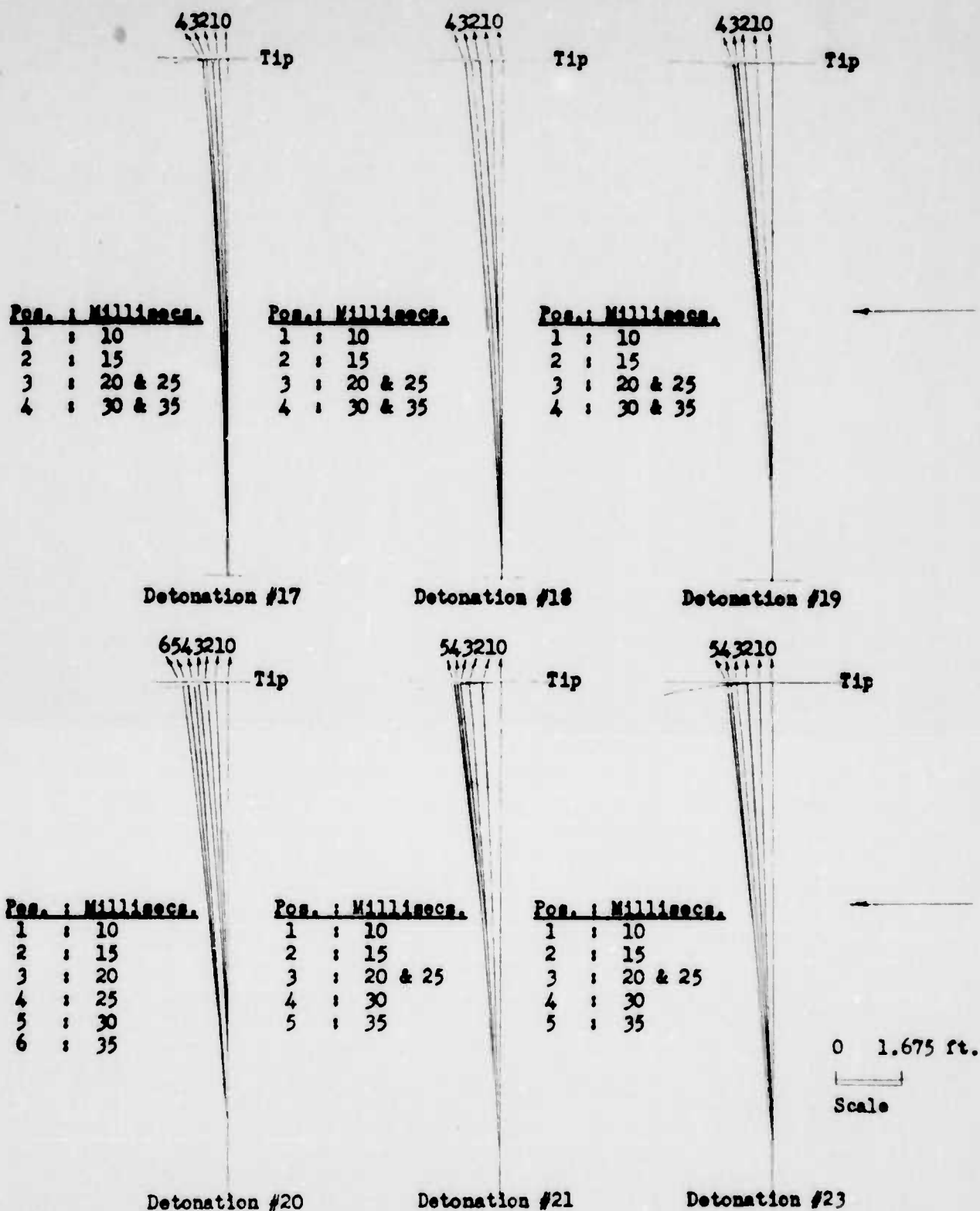
1 July 1952

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Damage to Aircraft by Blast - A rear view of the upper surface of the model F9F-4, LH-Outer wing panel showing damage to trailing edge and skin resulting from detonations #30 and #31. Note arrow on station #170 indicating extent of skin break.

Figure 48



MP9 - 49507

23 June 1952

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Damage to Aircraft by Blast. Deflections of the F9F RH outer wing panel, as traced from high speed motion pictures, versus times in milliseconds. The lines represent the under surface of the panel as seen from camera #1 (90° to line between wing and charge). The arrow indicates direction of approach of blast wave.

Figure 48

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NPG REPORT NO. 1058

Damage to Aircraft by Blast

HIGH SPEED MOTION PICTURES OF DETONATIONS 1 THROUGH 31
(86 ROLLS OF 16mm FILM UNDER SEPARATE COVER TO
MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
ATTN: MR. CHESTER H. BROWN)

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APPENDIX F

UNCLASSIFIED

NPG REPORT NO. 1058

Damage to Aircraft by Blast

PART A

SYNOPSIS

1. This is a partial report on the blast program undertaken in accordance with reference (a) under Task Assignment No. NPG-Re2c-36-1-52. The blast program was set up to furnish experimental data to supplement analytical work being conducted by the Massachusetts Institute of Technology under Bureau of Aeronautics Confidential Contract NOas 51-806-C. These data were to be obtained by firing charges of TNT up to 500 lbs. in weight at suitable distances from aircraft structures so as to subject these structures to increasingly severe blast pressures. The significant parameters of the blast wave were to be measured by means of electronic instrumentation and were to be accompanied by careful visual and photographic observation of the effects of the blast wave on the structure.
2. This report covers a series of 31 charges up to 500 lbs. in weight which were detonated in the period through 1 July 1952. Two outer wing panels from an F9F aircraft were used for all of these detonations.
3. In general the damage to the F9F wing occurred at a much higher level of blast pressure than had been anticipated, with first noticeable damage occurring at 11 psi (free peak overpressure). Damage to the wing from this point on was largely internal except for a dishing in of the skin of the movable leading edge. This damage reached proportions which might have endangered the aircraft in flight only at pressures of the order of 20 psi. The high speed motion pictures, as may be seen in Figure 49, showed overall bending of the wing to be considerable.
4. High speed motion pictures of the behavior of these structures when subjected to blast are being forwarded to MIT under separate cover.
5. Conclusions:
 - a. It is concluded that blast damage to the F9F wing (without ailerons, tip or flap) is largely caused by flexure of the wing as a whole, except for slight crushing of the leading edge.
 - b. It is concluded that the type of construction employed in the F9F wing has a very high resistance to damage by blast, but that results of tests on the wing panel alone do not necessarily imply that the aircraft as a whole will withstand similar blast pressures.

UNCLASSIFIED

Damage to Aircraft by Blast

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NPG REPORT NO. 1058

Damage to Aircraft by Blast

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NPG REPORT NO. 1058

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PART B

INTRODUCTION

1. AUTHORITY:

The work described in this report was undertaken in accordance with references (a) and (b) under Task Assignment Nos. NPG-Re2c-36-1-52, which was established by reference (a), and NPG-Re2c-36-2-52, which was established by reference (b).

2. REFERENCES:

- a. BUORD Conf ltr Re2c-GFS:rjb NP9 Ser 30243 of 7 Dec 1951
- b. BUORD Conf ltr NP9 Re2c-GFS:rjb Ser 40240 of 5 June 1952

3. BACKGROUND:

a. The Bureau of Aeronautics is currently engaged in various programs to obtain data on the response of Naval Aircraft structure to blast loads. A part of this program covering the analytical aspects of the problem is being conducted by the Massachusetts Institute of Technology under Bureau of Aeronautics confidential contract NOas 51-806-C. In order to determine adequately the effect of blast and associated phenomena on specific Naval aircraft, it is necessary to supplement the analytical work with experimental test work, of which this program is a part.

4. OBJECT OF TEST:

The object of this program is to investigate the effects of blast on structural components of aircraft and finally to determine the values of blast parameters which produce critical structural damage.

5. PERIOD OF TEST:

- | | |
|---|------------------|
| a. Date Project Letters | 7 December 1951 |
| | 5 June 1952 |
| b. Date Necessary Material Received | 4 March 1952 |
| c. Date Commenced Test (Preliminary Work, | 15 December 1951 |
| (Actual Detonations) | 23 April 1952 |

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-----PART CDETAILS OF TEST

6. DESCRIPTION OF ITEM UNDER TEST:

The structures covered in this partial report are new outer wing panels of the F9F aircraft. The first was a right hand panel and the second a left hand panel. No ailerons, flaps or wing tips were available. Details of the wing and its mounting may be seen in Appendix (D).

7. DESCRIPTION OF TEST EQUIPMENT:

The methods used in the recording of blast parameters are included as Appendix (A). A detailed description of the electronic instrumentation employed in the recording of blast parameters, together with notes and discussion of the instrumentation, is included as Appendix (C). In brief, electronic instrumentation involved the use of recording cathode ray oscillographs, with associated amplifiers, piezo-electric gages, and other equipment, to record:

- a. A time history of free overpressure.
- b. A time history of reflected overpressure.
- c. Free air peak overpressures by the velocity method.

In addition, three 16mm Fastax cameras were used to show the blast wave and the wing deflections. The lay-out of these cameras relative to the test area and to the structure is described in detail in Appendix (D).

8. PROCEDURE:

After preliminary testing of the instrumentation in the field, using small charges, a right-hand wing panel from an F9F aircraft was set up at the blast area and a series of detonations made, using charges ranging from 350 to 500 pounds of TNT. Charges and distances were varied so as to increase the free peak overpressure in increments of approximately 0.5 psi. The method of attachment of the wing and its orientation with respect to the charge is described in detail in Appendix (D). The schedule of detonations and other detailed information regarding them is included with recorded pressures and other data in Appendix (B). After each detonation, the wing was examined carefully for any evidence of damage, and deformations or breakages

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recorded. This procedure was followed until damage to the wing had proceeded to the point at which the aircraft probably could not have returned to base had it been in flight. A second F9F (left-hand) wing was then set up in the same manner. The charge weight and distance for the first detonation, using the second wing, were selected so as to give a blast pressure slightly less than that of the final detonation using the first wing. Successive detonations were designed to give increased pressures in suitable increments. A total of four detonations caused damage slightly greater than that of the first wing at the conclusion of its testing, and testing of the F9F wing was concluded at this point.

9. RESULTS AND DISCUSSION:

a. The detailed results of recorded blast parameters are included as Appendix (B). Appendix (A) includes explanatory matter and discussion of instrumentally recorded results from the point of view of their meaning and validity. In these data, each detonation is assigned a number in the chronological order of firing. These numbers are used to identify all data submitted in this report.

b. The results of wing damage assessment are shown in detail in Appendix (E). On each detonation where damage was evident, a form was prepared showing the exact location and nature of the damage. Photographs were taken whenever practicable as an aid in describing the damage.

c. In general, the damage occurred at a much higher level of blast pressure than had been anticipated. (First damage occurred at 11 psi free peak overpressure). Consequently, the initial detonations might have been designed to give higher pressures and many of them might have been eliminated. These initial detonations were not entirely wasted, however, as much valuable experience was gained in the recording of data, assessment of damage and conduct of the test in general.

d. The mechanism of the wing failure was also different from that anticipated. Due to the thick skin of the wing and the large number of supporting members, permanent deformations of the wing skin did not occur except in the hinged leading edge, and there only when subjected to very high pressures. The failure of the skin of the wing on the side opposite to the blast on detonation No. 28 was attributed to weakening and shearing of internal structure caused by the overall flexing of the wing. The high blast pressures required to damage the structure, while indicative of an impressive resistance to damage to aircraft by blast, may not be a true picture of the resistance of the whole aircraft. Failure of ailerons, flaps, canopy, or empennage might well have caused loss of the aircraft at much lower pressures.

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e. The final detonation on the second wing, which resulted in extensive damage, produced a free peak overpressure (30 psi) which was much greater than had been anticipated on the basis of previous work. Examination of high speed motion pictures of this detonation showed an irregularity in the blast which may account for the anomaly. A spear of flame (so called because of its sharp point and included angle of about 45°) was observed to pass the wing on the side opposite the cameras and quite close to the gage stands. Subsequent pictures of the explosions themselves have shown this spear phenomenon to be not uncommon, occurring to a greater or lesser degree in approximately half the detonations. Its effect is believed to be greater, the closer the approach to the charge. The particular combination of charge weight and distance used on this final detonation was used on a later detonation without a structure in place, but otherwise under closely similar conditions. A blast pressure of about 26 psi was recorded, indicating the variation to be expected from individual differences in detonations. Combined with the fact that the empirically determined curve of blast pressure plotted against reduced distance is quite steep in this region, such a large variation indicates the desirability of using longer distances and increased charge weights to obtain the blast pressures necessary to damage the F9F wing.

f. It is realized that the damage assessment data for this wing do not convey much in the indication of threshold damage, i.e., the damage which would not endanger the aircraft but which would necessitate repairs before resumption of routine flights. The nature of such damage to wings of this type is largely internal and must be deduced from evidence that requires a trained eye to detect and interpret. Closer attention will be given such evidence on future assessments in the light of results obtained to date.

PART DCONCLUSIONS

10. a. It is concluded that blast damage to the F9F wing (without ailerons, tip or flap) is largely caused by flexure of the wing as a whole, except for slight crushing of the leading edge.

b. It is concluded that the type of construction employed in the F9F wing has a very high resistance to damage by blast, but that results of tests on the wing panel alone do not necessarily imply that the aircraft as a whole will withstand similar blast pressures.

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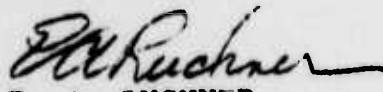
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