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A NEW LOOK AT AN OLD IDEA (U)

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A NEW LOOK AT AN OLD IDEA (U)

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ABSTRACT (CDI)

This report shows that it is within the state-of-the-art to design an airplane primarily intended to destroy light targets by the overpressure and dynamic pressure of its shock wave. Such an airplane would weigh about 600,000 pounds at take-off, would fly at M = 1.2 and would need 500,000 pounds of thrust at attack conditions.

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SUMMARY

The possibility of deliberately designing an aircraft to produce ground damage from its self-generated shock wave is reexamined in the light of (a) the recent development of terrain clearance radar which permits low altitude high speed flight, and (b) recently developed overpressure theories which permit rough studies of altitude and speed tradeoffs.

It is concluded that substantial ground damage could be produced by a 500,000 pound aircraft capable of flying M = 1.2 at altitudes of a few hundred feet or lower. This aircraft could produce overpressures greater than one psi covering a strip a half mile wide at least 30 miles long and possibly as much as 600 miles long. The length of the destructive path is fuel-limited, with the maximum distance occurring if M = 1.2 can be obtained without rocket boost. An overpressure of over three psi could be put on a strip 1000 feet wide. Still greater overpressures could be generated by (a) special aircraft shapes, (b) flying lower, (c) flying faster, (d) accelerating while over the target, or (e) flying several "shock sweepers" in formation to add their overpressures.

The airplane to weigh 500,000 pounds and fly at M = 1.2 would require around 500,000 pounds of thrust, the equivalent of twelve of our largest jet engines or eight large jets and two rocket motors for use during run-in. The configuration would have to be very unorthodox to keep frontal area small. Due to enormous fuel loads, poor L/D (= short range), speed mismatch between "shock sweeper" and aerial tanker, and need for water basing and overwater testing to preserve security, it is probable that the craft would have to be a seaplane and refuel from a ship or a submarine.

The study reported herein is a rough-order-of-magnitude analysis largely devoted to demonstrating the feasibility of a shock sweeper, and to recommend that others consider the new weapon system both from offensive and defensive standpoints.

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Introduction

Numerous accounts of damage resulting from the shock wave of a passing aircraft suggest using this mechanism as a nonlethal strike precursor. The practicality of such a system has been made feasible by the success of the terrain clearance auto-pilot currently in the F-111.

Data for this study consists of shock overpressure theory and experiment from Refs. 1, 2, 3, 4 and 5; the documented shock damage from a supersonic flyby at our Tonopah Test Range, and aircraft analysis based on the author's experience.

In brief, the inadvertent flyby at Tonopah resulted in incapacitating the range. Figures 1, 2, 3 and 4 show some of the damage. Windows were broken and glass driven into the living space, sometimes right through venetian blinds; many fluorescent light fixtures fell, sometimes the light tubes were shaken from them; some weak walls were cracked and moved, and some insulation peeled off. Due to a very small attendance at the range at the time of the incident, only one person was hurt, but it is safe to say that as a cohesive organization the range was inoperative for several hours. Still further, the anticipation of another such shock would make the staff apprehensive of flying glass and potential electrical hazard from wiring torn loose. An important and significant point is that in contradistinction to Las Vegas damage from early nuclear tests where glass was always sucked out by the vacuum phase, in this case at least, the glass was driven in. We will discuss the flight conditions after looking at overpressure theory, with final considerations of the basic design features of a shock sweeper and its probable use.

Theory

In Reference 1 an equation for the peak overpressure is given as

$$\left(\frac{\Delta p}{p_o}\right)_{max} = K_1 K_2 \left(\frac{L}{h}\right)^{3/2} \rho^{1/4} \sqrt{\frac{\beta}{2} \frac{C_L S}{L^2}} \qquad (1)$$

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Where $\beta = \sqrt{M^2 - 1}$

L = vehicle length, feet

h = flight altitude, feet

C_L = weight/qS

S = wing area, ft^2

q = dynamic pressure, lbs per sq/ft

$K_1 K_2$ = f(vehicle geometry, atmosphere. flight Mach number)

p_o = ambient static pressure

Equation 1 may be rewritten

$$\Delta p_{max} = K_1 K_2 \frac{1}{L^{1/4} h^{3/4}} \frac{(M^2 - 1)^{3/8}}{M} \left(\frac{p_o W}{\gamma}\right)^{1/2} \qquad (2)$$

Where W = aircraft weight, lbs, and γ = ratio of specific heats for air = 1.4.

In Reference 1 the accuracy of Equation 2 is well established by comparison with the actual ground pressures for an F-104 for which values of K_1 and K_2 were determined. The equation tells us that for maximum shock overpressure the sweeper should be as heavy as possible, as short as possible and fly as low as possible. The Mach number function peaks at M = 2.0, but in the section on "Design of a Shock Sweeper" it is pointed out that flight at M = 2.0 at sea level is probably beyond the state-of-the-art. M = 1.5 is tough but possible.

In Reference 1 the ground pressures for very low level (60 feet = h/L = 1.0) altitude correlate with the airplane shape. The shocks off the inlet, wing, and tail are clearly identified. At higher altitudes, say 100 body lengths, the shock and "vacuum" waves coalesce and an N-shaped pulse is formed.

Putting the F-104 dimensions into Equation 2 (W = 19,841 lb, S = 196 ft^2, L = 55 ft) we get

$$(\Delta p)_{max} = 2.75 \left(\frac{L}{h}\right)^{3/4} \frac{(M^2 - 1)^{3/8}}{M}, \text{ psi} \qquad (3)$$

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For the case of M = 1.2 we get:

h, ft	h/L	F-104 Δp max, psi	"500,000 lb F-104" Δp max, psi	"500,000 lb F-104" Scaled Height, ft
55	1.00	1.70	5.48	330
110	2.00	0.994	3.20	660
165	3.00	0.748	2.41	980
220	4.00	0.620	1.99	1320
275	5.00	0.509	1.64	1650
550	10.00	0.304	.98	3300

TABLE I

Agreement for the peak overpressure was poor at h/L = 1.00 in Reference 1, being about half when practice is compared with theory, but good at higher altitudes. Since the sweeper to be proposed will fly well out of the h/L = 1.0 regime, we will use the theoretical values.

The column for the "500,000 lb F-104" assumes the same shape as an F-104, but a 330 foot length. Bearing in mind that the F-104 was designed as a fighter with everything in mind except making a strong shock wave, the overpressure values must certainly be considered minimum.

From similarity laws, the same overpressures will exist at the same heights measured in body lengths. This, of course, gives higher, wider sweep paths for the longer and heavier aircraft, or alternatively, greater maximum pressures.

The second point of interest is lateral spread of pressure. Reference 1 suggests that $\Delta p_{max}/2$ occurs when y/h = 1.0. That is, if a flight at 500 feet produces 1 psi directly beneath it, it will produce one-half psi or more out to 500 feet on each side of the flight path. Values from Table I indicate that at 1320 feet there will be 2 psi overpressure directly below the sweeper, and 1 psi (enough to break essentially all windows) at the outer edges of a strip one-half mile wide. Several methods of increasing these values--possibly by a factor of 2.0 or more--are in a later section.

Experiment

We have already mentioned that Reference 1 shows excellent correlation between theory and practice above h/L = 1.00. It now remains to correlate aircraft overpressures and damage.

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On September 25, 1965, an exuberant pilot of an F-4 buzzed the Command Post at the Tonopah Test Range and inadvertently went supersonic. Unfortunately we have no accurate data as to his flight speed, flight path or altitude. The estimates from three eyewitnesses vary from "2000 to 3000 feet over the Command Post" to "low, but not over the Command Post."

From Table I, an F-104 at M = 1.2, directly overhead at 550 feet would have produced an overpressure of 0.304 psi. Assuming double the weight and about the same length for an F-4, the overpressure becomes 0.42 psi. The fact that no witness places the airplane directly overhead and low, suggests the actual overpressure was less than 0.4 psi; possibly 0.2 psi. Photos of the damage (Figures 1, 2, 3, 4) were studied by an expert in nuclear blast damage who estimated the damage comparable to that caused by 0.4 to 0.5 psi from a small nuclear blast, and close to that from an F-104 at M = 1.05 and 300 feet, as determined from Reference 3. (In Reference 3, F-104 data is some higher than that of Reference 1.) At any rate we must conclude that 0.4 psi will disrupt work. An equation for the number of windows broken per thousand windows (Reference 2)

$$N_{1000} = 3.71 \times 10^{-3} A^{1.22} \Delta p^{2.78} \qquad (4)$$

Where A = window area, sq/ft

Δp = overpressure, millibars

shows that 0.4 psi (= 27 millibars) will break about 20% of the windows which is in the ballpark of the damage. Since a smaller percentage of windows were broken, one could argue again that TTR damage was due to from 0.2 to 0.3 psi.

For any overpressure at sea level there is a corresponding dynamic pressure and wind velocity. These values are as follows:

Peak overpressure psi	Peak dynamic pressure, psi	Maximum wind velocity, mph
0	0	0
2	0.1	70
5	0.7	160
10	2.0	290
20	8.0	470

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Damage resulting from an explosion may be crushing from overpressure (windows, ceilings, eardrums) or being thrown about by blast (People, jeeps). In either case the duration of the effect is significant. From the Tonopah damage (which was more than reasonable from sonic boom theory) and from measured airplane shocks generated at low level (multiple peaks, possible 200 milliseconds duration), it seems possible that damage by airplane made shocks correlate with say 1KT explosions. These values of damage are in the Table below, and are proposed as first cut sonic boom damages.

Δp, psi	Damage
0.5	Face on windows out, some side windows broken.
1.0	All windows gone, ceilings down, roof joints broken, some dwelling damage.
2.0	Some buildings collapsed, parked aircraft damaged.
5.0	Some eardrums broken, many buildings collapsed.
7.0	Many eardrums broken, most buildings extensively damaged, many destroyed.

It will be seen that an oversized streamlined F-104 sweeper can break windows, damage dwellings, damage parked aircraft and break some eardrums using only state-of-the-art values.

Design of a Shock Sweeper

While the layout, weight and balance and performance calculations for a shock sweeper comprise a task well beyond the scope of this note, it is of interest to comment on what the general design features must be for an aircraft intended to create maximum shock damage.

1. Basic parameters.

The basic parameters affecting shock strength (Equation 2) are shape, weight, length, height of flight path above ground, flight Mach number, and atmospheric static pressure (about which we can do nothing). The shock strength parameter peaks at M = 2.0, but it is clear that, given a total thrust one would not design a clean aircraft to fly at M = 2.0 in contradistinction to a "blunt" one to fly at M = 1.2 or so. This is to avoid losses that increase with speed but do not contribute to the shock strength (skin friction, engine pressure-recovery loss, etc.).

One parameter within our control is weight. Other things being equal, shock strength increases with $W^{\frac{1}{2}}$. The shock sweeper should

clearly be the heaviest aircraft possible. This suggests something of the order of the C5A, 600,000 pounds at take-off, 500,000 pounds over the target. The large size also helps with range.

For very low level cruise, a high wing loading (say 140 psf) would be reasonable, and for low supersonic drag a long wing chord. This points toward an aspect ratio of 4.0 or so and a straight (unswept) leading edge--a configuration that gives maximum shock strength at M = 1.2. The low aspect ratio would have to be heavily flapped to avoid high angles of attack for landing. It would also be hard on range which will be discussed after we cover power considerations. The large trim changes which occur when passing through M = 1.0 suggest a large horizontal tail--perhaps 25 or 30 percent of the wing area as compared to a more normal 18 to 20 percent. It should probably be swept to remain sub-critical.

2. Power requirements and performance.

The shock sweeper will require enormous thrust. For a rough number, the streamlined F-4 uses about 35,000 pounds of thrust at M = 1.2, at a weight of 35,000 pounds. If our 600,000 pound (take-off) aircraft is reduced to 500,000 pounds for run-in, it will still need 500,000 pounds of thrust, provided it can be made as streamlined as an F-4. This would call for two 250,000 pound jets which could be buried in the fuselage. Since such engines do not exist, we must look elsewhere for 500,000 pounds of thrust. We could use 12 of our largest jet engines (40,000 pounds each), or eight 25,000 pound jets plus two 150,000 pound rockets to use during run-in. It is not clear how one could mount eight engines plus two rockets. The B-58 large wing area plus engines-in-pods is a configuration recommended for <u>reducing</u> sonic boom, not increasing it. The need for a short span unswept wing suggests four engines on each side, or possibly pylon mounted on the fuselage. The rocket engines would have to be rear-mounted to provide a clear path for the efflux and a reduced yawing moment in case one misfires.

If the gross weight is composed of 250,000 pounds of airframe and 350,000 pounds of fuel we can hypothesize the following for cruise and run-in.

(a) Cruise. Assume 200,000 pounds of jet fuel, average gross weight of 500,000 pounds, and L/D = 4.0. The required thrust will be 125,000 pounds which at a specific fuel consumption of 0.7 pounds of fuel per pound of thrust per hour gives about two hours radius, or around 1000 miles.

(b) Run-in. Assume 150,000 pounds of liquid rocket fuel and a specific impulse of 300 seconds. We would hence use 1000 pounds per second (for 300,000 pounds of thrust) and have enough fuel for 150 seconds of run-in (= 30 miles, neglecting acceleration time).

If methods could be found to use jet engines only (with afterburners), the run-in time could be increased to 15 minutes (= 200 miles) if present time limits for afterburners are observed, or possibly 600 miles if they are not.

The short cruising radius of the shock sweeper, its enormous fuel load and probable incompatibility with tanker cruise speeds suggests using a seaplane configuration so that refueling could be accomplished by tanker-ship or submarine. If this type of craft is selected, engine location becomes more critical to avoid spray ingestion during take-off and landing, and all jet engines would have to be located well forward. In order to permit a smooth body contour for low drag retractible hydrofoils would be needed. Further arguments for a seaplane are in another section.

Continuing our assumptions of a high wing loading (140 psf at cruise) the wing area works out at 3500 sq/ft with a span of perhaps 120 feet and a chord of 30 feet. Even with the low altitude auto-pilot, little range benefit would accrue from flying low enough to use ground effects.

The Shock Sweeper as a Weapon System

From looking at the overpressure ranges of the proposed shock sweeper--up to about 5+ psi--it is apparent that it would not be a lethal system, except in the sense that people could be killed when their houses fell in. But consider the threat if the Russians had one. They could knock down a strip in a dozen cities in a slave country, deafen a few thousand people and demand any action they desired. Repeated sweeps would produce a panic-stricken populace. People can't work effectively wearing earplugs, nor stay away from windows, nor live under continuous bombardment by shock waves. For the first time it would be possible to punish a populace; just beat them with shock waves until they give up.

Effects of a shock sweeper would be somewhat different between cities and and the countryside.

Against cities, a high (2500 foot) sweep would break out windows, cut some personnel, and in winter probably end up with a lot of frozen

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and burst water pipes. A high sweep across our eastern megalopolis would be a real panic generator. Low sweeps at higher pressure would deafen great numbers of people, (making communication between them very difficult) and knock down dwellings.

Against the general countryside, barns could be flattened, probably some animals killed, and maybe ripe grain crops knocked on the ground. Possibly personnel mines would be triggered. While the jungle canopy would be an attenuator, possibly enough overpressure would get through to bend radar vans and reduce troop effectiveness. The sweeping is so vast that targets do not need to be seen or identified. Five changes could be used to increase the overpressures shown in Table 1.

1. Short the aircraft. This could yield ten percent higher pressures.

2. Specialize the design for shock sweeping only. The possible gain is unknown.

3. Fly faster. The drag coefficient of a straight wing falls so rapidly above $M = 1.0$ that a higher speed might be possible. $M = 1.5$ would give 20 percent more Δp than $M = 1.2$.

4. Accelerate over the target. As shown in Reference 5, accelerating flight causes a coalescing of shock waves which under some circumstances ends up with three times the unaccelerated value (but less duration). It is conceivable that a sweeper could dive at a hard target to destroy it, or accelerate over it.

5. The lateral fall-off of overpressure is so gradual that a wing-tip to wing-tip formation of two planes could amost double single plane pressures.

Development, Flight Test, and Security

The problems of developing a radical airplane, conducting flight tests which would damage people and things below it, all the while maintaining secrecy are many, but not insoluble. Indeed the previously developed concept of a shock sweeper seaplane points toward this configuration. The sweeper seaplane could be assembled and flown from a remote base, using one of our great lakes or possibly the Gulf of Lower California, or the ocean. Fishermen could be moved out on some pretext and the aircraft taxied out at night and test flown in the early morning with air transport diverted from overhead. Sonic booms could be explained as gunfire or such.

Flights over land which would expose the odd craft to observation of hunters and sheepherders would not be too damaging to security, but knocking down huts and breaking eardrums would.

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No engineering limitations prohibit the development of a heavy airplane specifically designed to produce shock waves strong enough to break windows, collapse weak structures, and break eardrums. Such an aircraft would be unorthodox in configuration to provide for sufficient thrust, needing eight large jet engines and additional rocket boost.

A shock sweeper would be a fearsome weapon; in general a city killer. Moderate altitude sweeps would break windows and tear down ceilings and lights, and lower sweeps could collapse some buildings and produce deafness.

As with any new weapon system, more data is needed on (a) actual shock pressures produced and (b) the damage levels incurred by this specific type of shock wave.

Overpressures given in this report may be increased due to the sweeper's special shape, by flying faster than M = 1.2, by accelerating as the target is flown over, or greatly increased (doubled) by a formation of sweepers.

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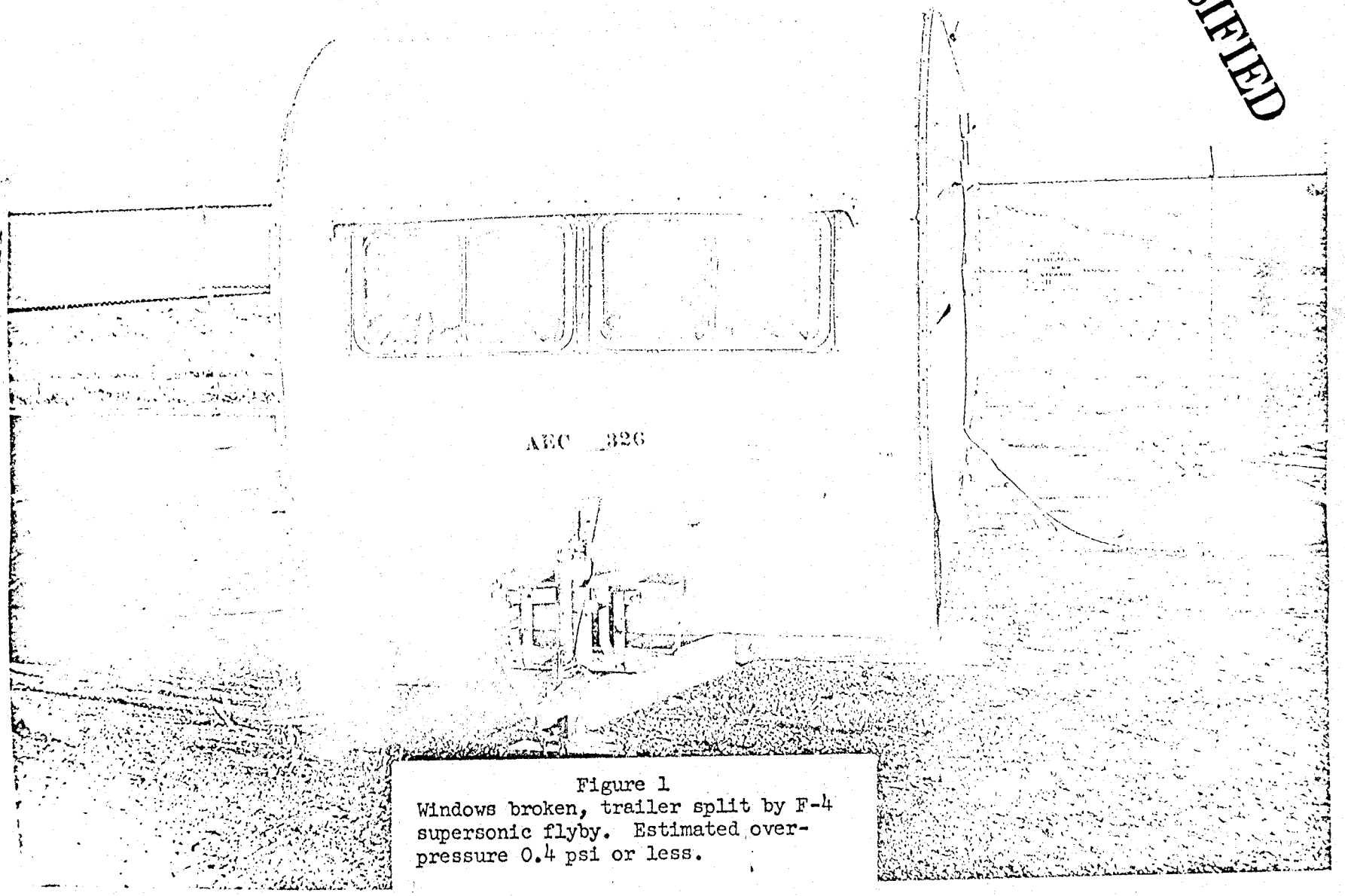

Figure 1
Windows broken, trailer split by F-4 supersonic flyby. Estimated over-pressure 0.4 psi or less.

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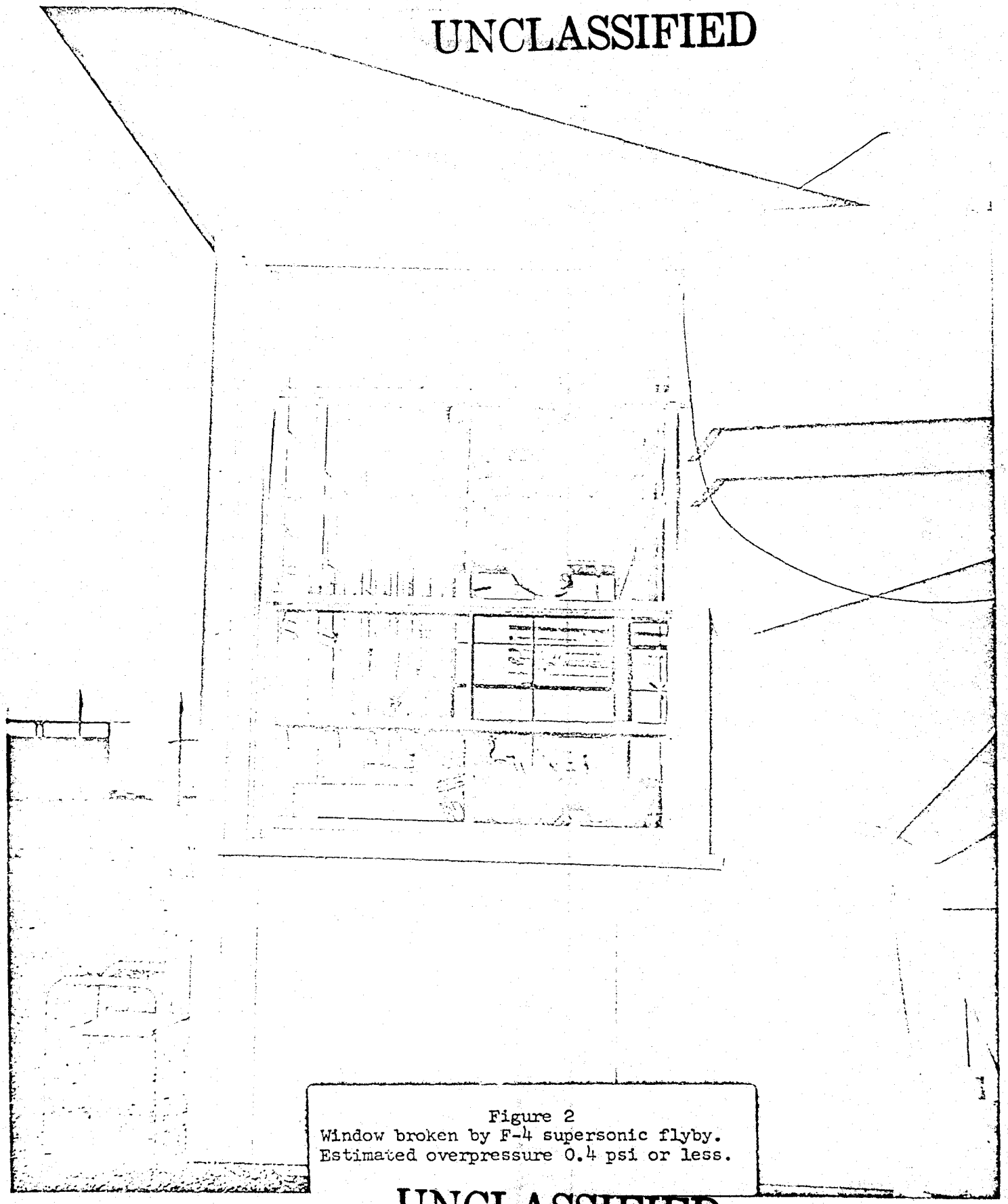

Figure 2
Window broken by F-4 supersonic flyby.
Estimated overpressure 0.4 psi or less.

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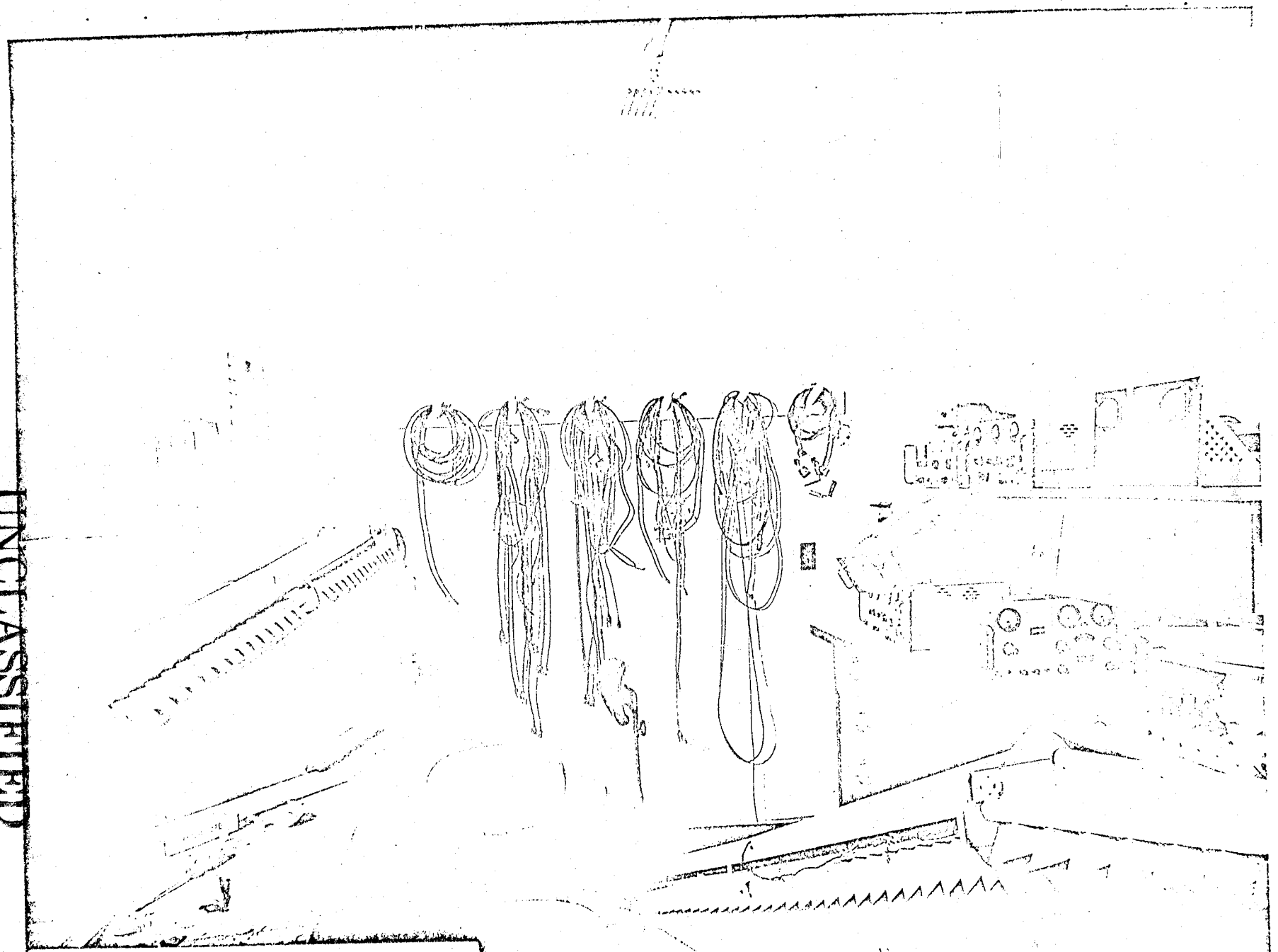

Figure 3
Fluorescent fixtures and other damage caused by F-4 supersonic flyby.
Estimated overpressure 0.4 psi or less.

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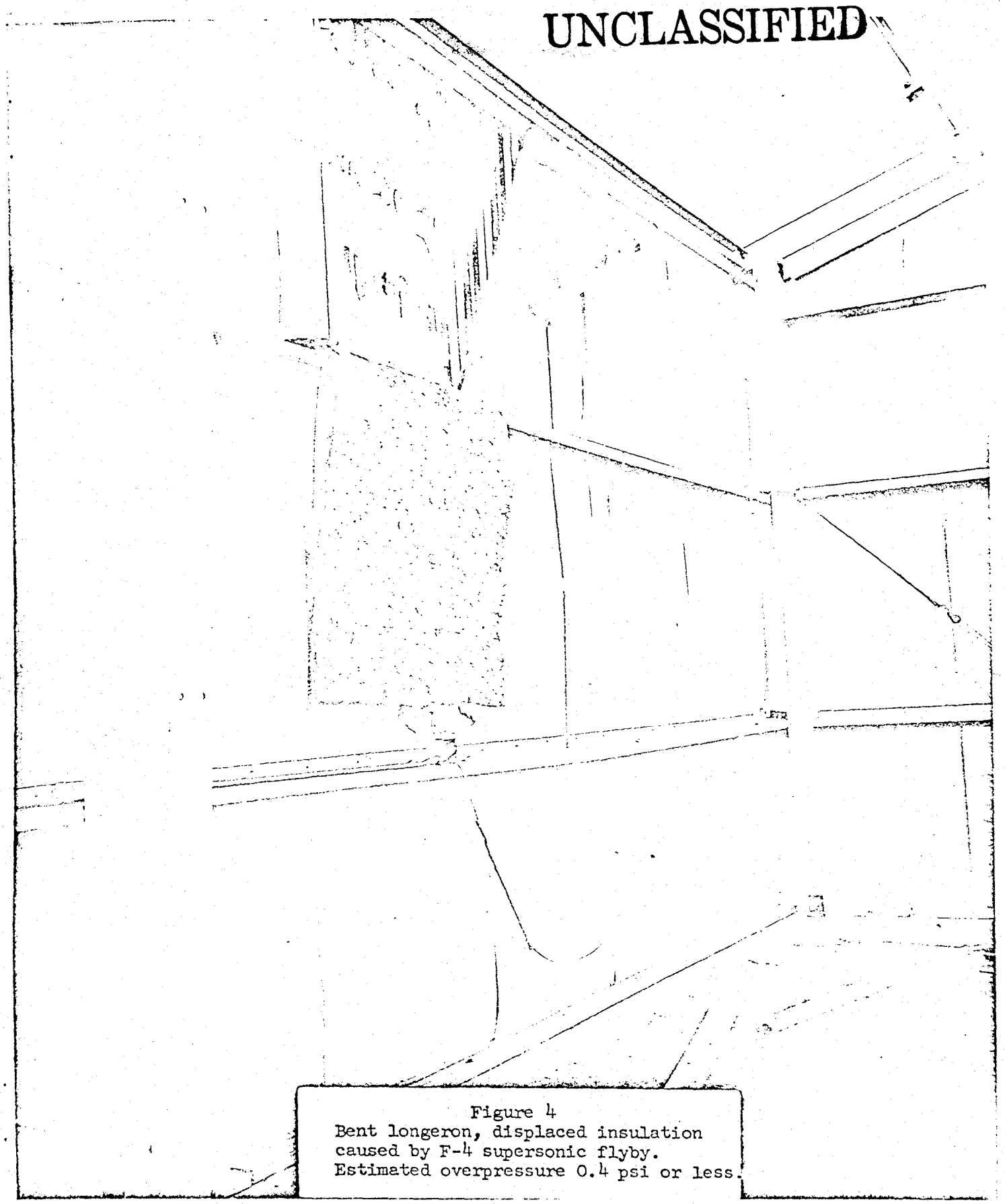

Figure 4
Bent longeron, displaced insulation caused by F-4 supersonic flyby. Estimated overpressure 0.4 psi or less.

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