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BIRD INGESTION TESTS
OF AN
ALLISON T-56 TURBINE ENGINE
(CIVIL MODEL 501-D13)

FOR LIMITED DISTRIBUTION

by

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SUMMARY

This report covers the effects of bird strikes directly into the inlet of an Allison T-56 turbine engine. The tests were conducted in cooperation with the Allison Division of General Motors Corporation.

The Allison engine, as originally presented for the tests, structurally will withstand bird strikes at speeds up to approximately 200 miles per hour (mph). The engine, as revised, will withstand bird strikes at speeds up to approximately 290 mph.

During all tests on the running engine a momentary blockage of the engine inlet duct existed upon impact causing either a flame-out or excessive turbine inlet temperatures. The flame-out condition was associated primarily with the higher speed impacts. In addition, the momentary inlet blockage condition was further aggravated during tests in which no flame-out occurred by the semi-permanent blockage of the aft stages of the compressor with a fibrous material which collected on the leading edges of the rotor and stator blades.

INTRODUCTION

The bird ingestion tests of an Allison T-56 turbine engine were conducted at the Civil Aeronautics Administration, Technical Development Center, Indianapolis, Indiana, from August 8 to September 13, 1956, and from October 11 to October 17, 1956.

The purpose of the tests was to determine the effects of bird impacts on the structural components of a turbine-type engine if the bird strikes directly into the engine intake.

The tests were conducted with the assistance of Mr. George V. Bianchini, special test projects engineer for the Allison Division of General Motor Corporation.

TEST INSTALLATION

The tests were conducted on an Allison Model T-56 turbine engine, a military version of the Allison Model 501-D13 engine. The Model T-56 engine incorporates a 14-stage axial flow compressor, a cannular-type combustion chamber, and a four-stage axial flow turbine coupled directly to a gear box which in turn drives a propeller. It is a constant speed engine with a turbine rating of 13,820 revolutions per minute (rpm) at cruise power. The propeller is geared down to a normal propeller operating speed. The Model 501-D13 engine is essentially the same as the T-56 engine, except for features which allow the turbine speed to be reduced to 10,000 rpm for ground idling. The maximum horsepower rating for the Model T-56 engine is 3750 equivalent shaft horsepower (eshp). For all tests the engine was supported on a welded channel structure built up from and bolted securely to the test cell floor as shown in Fig. 1.

A compressed air gun having a barrel 42 feet long with an inside diameter of six inches was used to propel freshly killed chicken carcasses weighing very close to four pounds into the engine. This gun, having accurate muzzle velocity control, is capable of propelling four pound chicken carcasses over a wide range of muzzle velocity. To date the gun has been calibrated up to a muzzle velocity of 625 mph.

During the initial tests a dummy engine incorporating a production guide-vane ring was tested. This guide-vane ring, as damaged in the tests, is shown in Fig. 2. The bird carcass velocity at which failure of this assembly occurred was used as a factor in determining the maximum bird carcass velocities for the running-engine tests. For the running-engine tests an external supply of oil together with a cooling unit was used. The JP-4 fuel was stored in an external 200-gallon tank and was delivered at a pressure of 20 to 30 pounds per square inch (psi) to the engine through 3/4-inch copper tubing. A turbine-engine ground-starting unit was utilized in the tests. Figure 3 shows the complete engine test arrangement. The engine appears at the left while the barrel of the compressed air gun for propelling the chicken carcasses into the engine appears at the right. The control panel and engine instrument arrangements are shown in Fig. 4.

TEST PROCEDURE

Freshly killed chicken carcasses were propelled into the intake of the engine by means of the compressed air gun. For each test the chicken carcass was contained in a heavy paper bag, backed up by a Styrofoam plastic plug 6 inches in diameter and 4 inches in length. This arrangement gives the appearance of a projectile approximately 12 inches in length and 6 inches in diameter. A cut-open view of the projectile is shown in Fig. 5. The plastic plug was sliced longitudinally, nearly its full length, into 32 equal parts so that it would break up readily upon impact. The combined weight of the chicken, plug, and bag was 4 pounds plus or minus 2 ounces. The weight of the plug and bag was about 2 ounces. Points of impact in the engine inlet duct were determined by sighting through the gun barrel at the target through "peep sights" temporarily placed inside the barrel for this purpose.

On the dummy engine, the point of impact chosen corresponded generally to the upper right quadrant of the engine inlet as viewed from the front of the engine. The first 16 tests were conducted on this engine. Following Test No. 3 the inlet air duct was removed and the bird carcasses were propelled directly into the compressor inlet.

On the running engine, tests were made with the center of impact at the right hand section of the inlet duct as viewed from the front of the engine. The inlet air duct was installed on the engine for all of these tests, Tests Nos. 17 to 27 inclusive. Velocity measurements were obtained by the bird carcass breaking two pairs of fine steel wires after leaving the muzzle of the gun. One pair of wires was connected to a direct-reading counting chronograph, while the other pair was connected to a recording oscillograph. A third measurement of velocity was obtained through use of a high speed camera. This photographic method was used to determine the speeds for Tests Nos. 13, 16, 17, 18, 20, 24, and 27, because at high speeds in particular, the paper bag containing the bird carcass and Styrofoam plug failed partially, and there was an apparent break-up or some separation of parts of the projectile inside the gun barrel. This produced erroneous readings from the chronograph and oscillograph, necessitating the use of the high speed film alone for obtaining bird carcass velocities.

It was found necessary to remove the upper and lower casing of the compressor section after Tests Nos. 17 and 18 in order to remove the fibrous material clogging the stator blades. In subsequent tests the engine was cleaned by introducing crushed walnut shells into the intake duct with engine rotation motivated by the ground starting unit. The abrasive action of the crushed shells cleaned the engine to the extent that the turbine inlet temperature was reduced to operational limits.

After Test No. 18 the operational engine was returned to the Allison plant for replacement of damaged parts and for cleaning. At that time the inlet guide-vane assembly was replaced by another production assembly which had been improved by better quality control. In addition, the 14 stator blade assemblies were replaced by new assemblies which were strengthened by the employment of a better method of brazing the ends of the stator blades to the inner and outer retaining rings.

TEST RESULTS

The conditions and results of the individual impact tests are as follows:

Test No. (Dummy-Engine Tests)	Date	Projectile Velocity (mph)	Projectile Weight
1 to 16 incl.	8/15/56 to 8/29/56	65 to 380	4 lbs. ±2 oz.

These tests were performed on a dummy engine to determine the velocity at which prohibitive structural damage would occur to the inlet guide vanes. It was found that a direct hit would cause prohibitive damage in the velocity range of 335 to 380 mph. It was decided that tests on the running engine should be limited to velocities under 320 mph to prevent excessive damage to the compressor section which could result if pieces of the inlet guide vanes were forced through the compressor section. It was found, furthermore, that a bird strike directly into the air inlet duct of this engine at speeds of 320 mph or greater will deform the duct considerably, necessitating repairs. This air inlet duct is not an engine part, but is a part furnished by the airframe manufacturers. The results of two tests at a carcass velocity of 330 mph are shown in Figs. 6 and 7. Figure 8 shows the results of a test at a carcass velocity of 380 mph.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
17	9/6/56	177	4 lbs. 1 oz.

The carcass was propelled into approximately the right hand section of the engine inlet as viewed from the front of the engine. The engine flamed-out due to air passage blockage. The rear edges of 6 inlet vanes from the 12 o'clock to the 2:30 o'clock positions of the inlet were bent clockwise.

Several first-stage rotor blades were damaged slightly (nicked at the leading edge) and the edges toward the outer ring were bowed slightly. One inlet vane at a position of 11 o'clock was bowed.

The engine was started but excessive temperature at the turbine inlet was experienced during the run-up. The cover was taken off the compressor section to determine the cause of the excessive temperature. The stator blades of the last 4 stages which have a high solidity factor were found to be clogged near the casing with a fibrous material made up of chicken pin feathers, grease, and oil matted together. A considerable amount of this material was found clinging to the leading edges of the stator blades. Moreover, all of the rotor blades except those of the first stage, were coated on the under side with the fibrous material. Results of this test are shown in Figs. 9, 10, 11, and 12. Figure 9 is typical of the inlet air duct blockage encountered in these tests.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
18	9/13/56	213	3 lbs. 3 oz.

Upon impact by the chicken carcass the engine "torched" (flamed-out and relighted itself in rapid succession). The engine then was stopped by the operator, rather than allowing it to "flame-out" as in Test No. 17. Major damage to the upper set of first-stage compressor stator blades was apparently caused by the solid parts of the bird collecting in the area between the first-stage rotor and stator blades. The entrance vanes and first-stage rotor blades were not damaged appreciably beyond the damage caused by the previous test. It appeared that the upper-half section of the first-stage stator blades had attempted to rotate along with the rotor blades. Some damage was detected between the second-stage rotor and stator blades to the extent that the trailing edges of a few of the rotor blades were bent counter-clockwise and the leading edges of a few stator blades were bent clockwise as viewed from the front of the engine. Views of the engine following this test are shown in Figs. 13 and 14. Figure 13 shows typical air duct blockage encountered in these tests.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
19	10/11/56	150	4 lbs. 0.5 oz.

The engine did not flame-out upon impact of the bird carcass but was shut down due to excessive temperature in the turbine inlet. The trailing edges of the entrance blades were bent clockwise in three sectors. The leading edges of the first-stage rotor blades were bent counter-clockwise at the tips. The results of this test are shown in Fig. 15. This was the first test on the improved inlet guide-vane assembly.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
20	10/11/56	166	4 lbs. 1.5 oz.

The engine flamed-out upon impact by the bird carcass. No increased damage to the engine over that of previous tests was noted. A view of the engine through the air inlet duct following this test is shown in Fig. 16.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
21	10/16/56	143	4 lbs. 1.5 oz.

The engine did not flame-out, but was shut down due to excessive temperature in the turbine inlet. There was slight structural damage to the inlet vanes near the 2:30 o'clock position as viewed from the front of the engine. The chicken and plug blocked off two sectors of the air inlet duct of the engine without flame-out. A view of the engine through the air inlet duct following this test is shown in Fig. 17.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
22	10/16/56	184	3 lbs. 15.5 oz.

The engine flamed-out upon impact of the chicken carcass. The damage to the engine progressed rearward to the first-stage stator blades. The tips of the first-stage rotor blades were bent further in the counter-clockwise direction as viewed from the front of the engine. Crushed walnut shells were used to clean the engine. A view of the engine through the air inlet duct following this test is shown in Fig. 18.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
23	10/16/56	162	4 lbs. 0 oz.

The engine did not flame-out upon impact of the chicken carcass, but was shut down due to excessive temperature in the turbine inlet. The damage to the first-stage stator blades and the first-stage rotor blades was increased over the previous tests. The entrance vanes also suffered additional damage. See Fig. 19.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
24	10/16/56	212	2 oz. (Styrofoam Plug and Bag Only)

The engine did not flame-out upon impact of the projectile, but was shut down due to excessive temperature in the turbine inlet. The engine ingested all of the Styrofoam plug and paper bag with no apparent increase in structural damage over that of previous tests. See Fig. 20.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
25	10/17/56	35	4 lb. 0 oz. (chicken only)

Following the impact of the chicken carcass, excessive temperature was approached and the engine was shut down. No further damage to the engine was observed. See Fig. 21.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
26	10/17/56	103	4 lbs. 1 oz.

The engine did not flame-out after impact of the chicken carcass, but was shut down due to excessive temperature in the turbine inlet. No further damage to the engine was observed. See Fig. 22.

Test No. (Engine Operating)	Date	Projectile Velocity (mph)	Projectile Weight
27	10/17/56	289	4 lbs. 2 oz.

The engine flamed-out shortly after impact of the chicken carcass. The first-stage stator blades in the upper section all were bowed into a U-shape at the center indicating that the blades attempted to rotate with the first-stage rotor blades. The tips of the second-stage rotor blades were bowed slightly and the leading edges of the second-stage stator blades were rolled back slightly. It is doubtful whether the engine could have been restarted after this test. See Fig. 23.

CONCLUSIONS

As a result of the dummy-engine tests it is concluded that:

1. The inlet guide vanes of the dummy engine are not able to withstand a direct impact of a 4-pound chicken carcass at speeds in excess of 320 mph without appreciable deformation. At a speed of approximately 335 mph a direct hit on the inlet vanes can result in failure of one or more of the vanes in such a way that pieces of the vanes are likely to be driven into the compressor area of the engine. With the air inlet duct installed, a direct impact of the guide-vane assembly is highly improbable due to the curved contour of the duct.

2. The air inlet duct will be deformed appreciably by the impact of a 4-pound chicken carcass at a velocity of 320 mph or greater. It is believed that the deformation experienced at this velocity will not necessarily cause an immediate hazardous condition in flight; this has not been substantiated definitely, however, by any flight tests.

As a result of the running-engine tests, it is concluded that:

1. The Allison T-56 engine, as originally tested, can ingest a 4-pound chicken carcass at speeds up to 200 mph without excessive structural damage to the engine itself. At speeds over 200 mph structural damage requiring the replacement of the first-stage rotor and stator-blade assemblies probably will result.

2. The Allison T-56 engine, as modified during these tests by installation of an improved inlet guide-vane assembly and higher strength

stator-blade assemblies, can ingest a 4-pound chicken carcass at speeds up to 290 mph without excessive structural damage to the engine. At speeds in excess of 290 mph two factors are involved which may prove critical; that is, necessitate a shut-down. The first is manifested by fairly severe structural damage to the first-stage rotor and stator-blade assemblies. The second consideration is manifested by the probability of complete failure of a guide vane. This type of failure would result in severe damage to the compressor and would undoubtedly require a shut-down of the engine.

3. A condition of excessive temperature in the turbine inlet area can occur upon impact, at all speeds tested, which would necessitate an immediate shut-down of the engine. The high inlet temperature is caused in part by momentary blockage of the inlet air duct, and in part by the collection of fibrous material on the under side of the rotor blades and in the latter stages of the compressor stator-blade assemblies. Both of these conditions cause compressor stall with the accompanying rise in turbine inlet temperature. The automatic control of the compressor bleed valves and fuel/air ratio in an operational aircraft would help alleviate this situation.

The tests described in this report are considered to be quite severe because it is improbable that a bird would enter the air duct without being broken up to some extent by the propeller during actual flight conditions.

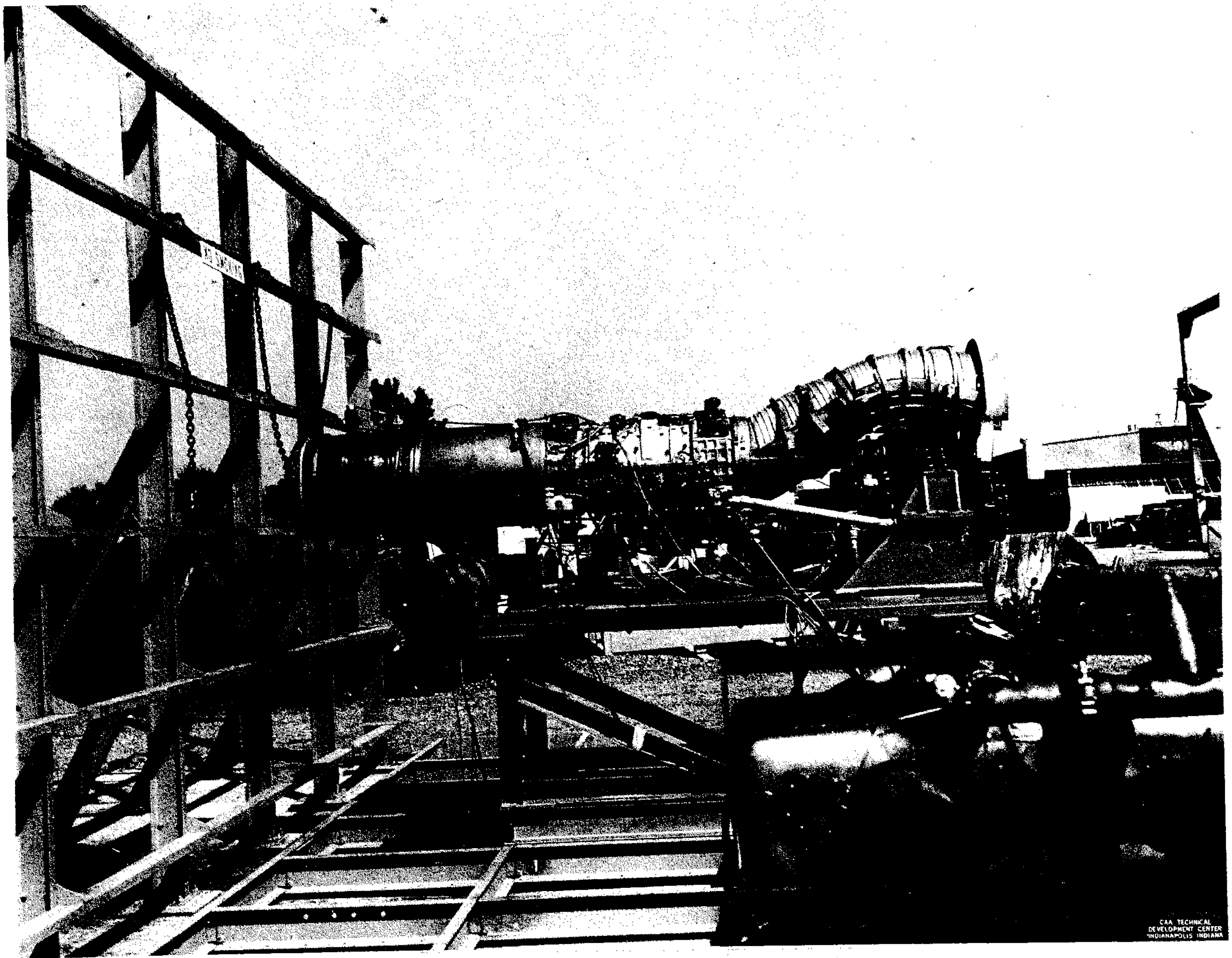

Fig. 1 Engine Mounting Arrangement

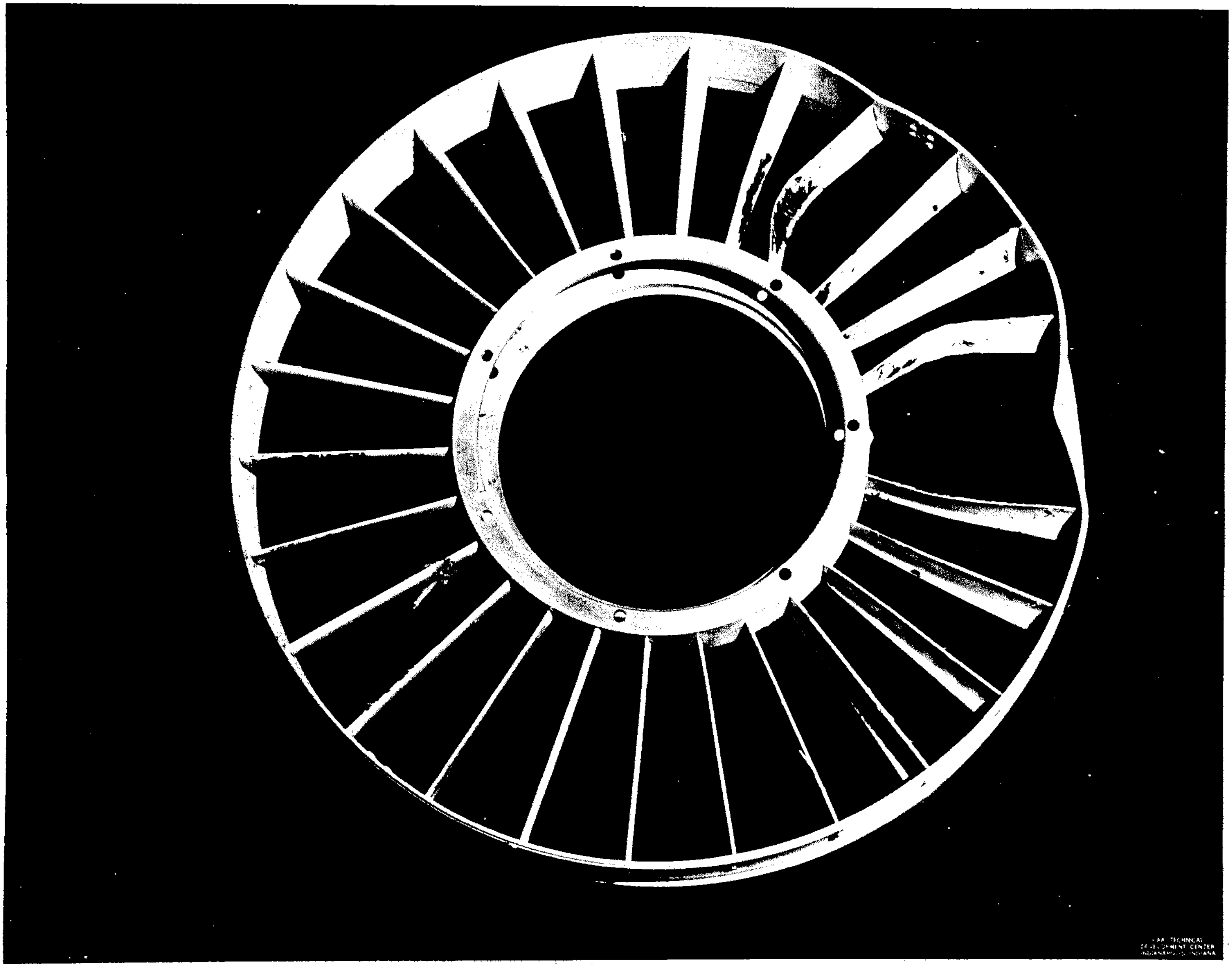

Fig. 2 Test No. 13 - 8/28/56 - Projectile Velocity 335 mph

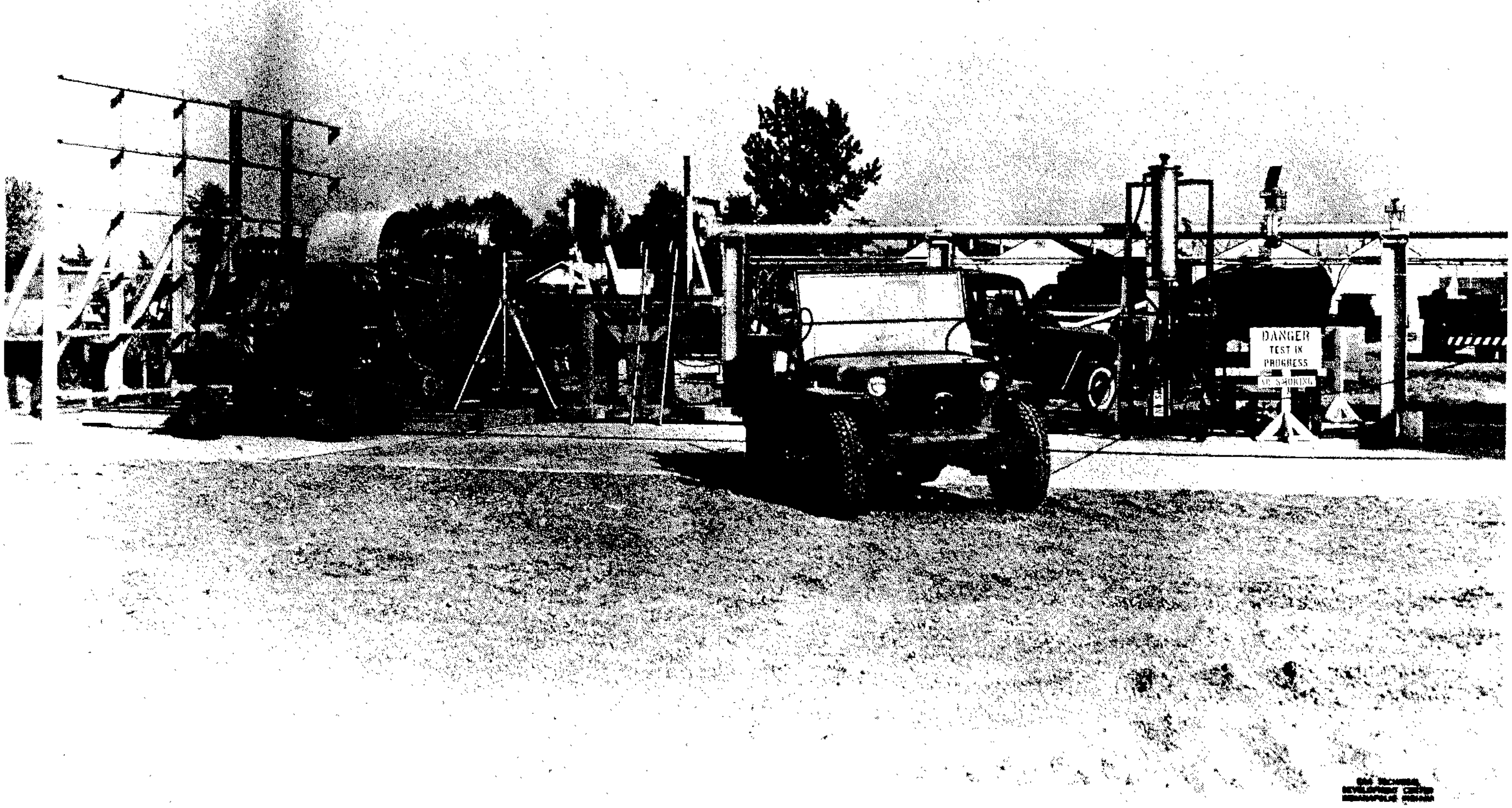

Fig. 3 Engine Test Setup

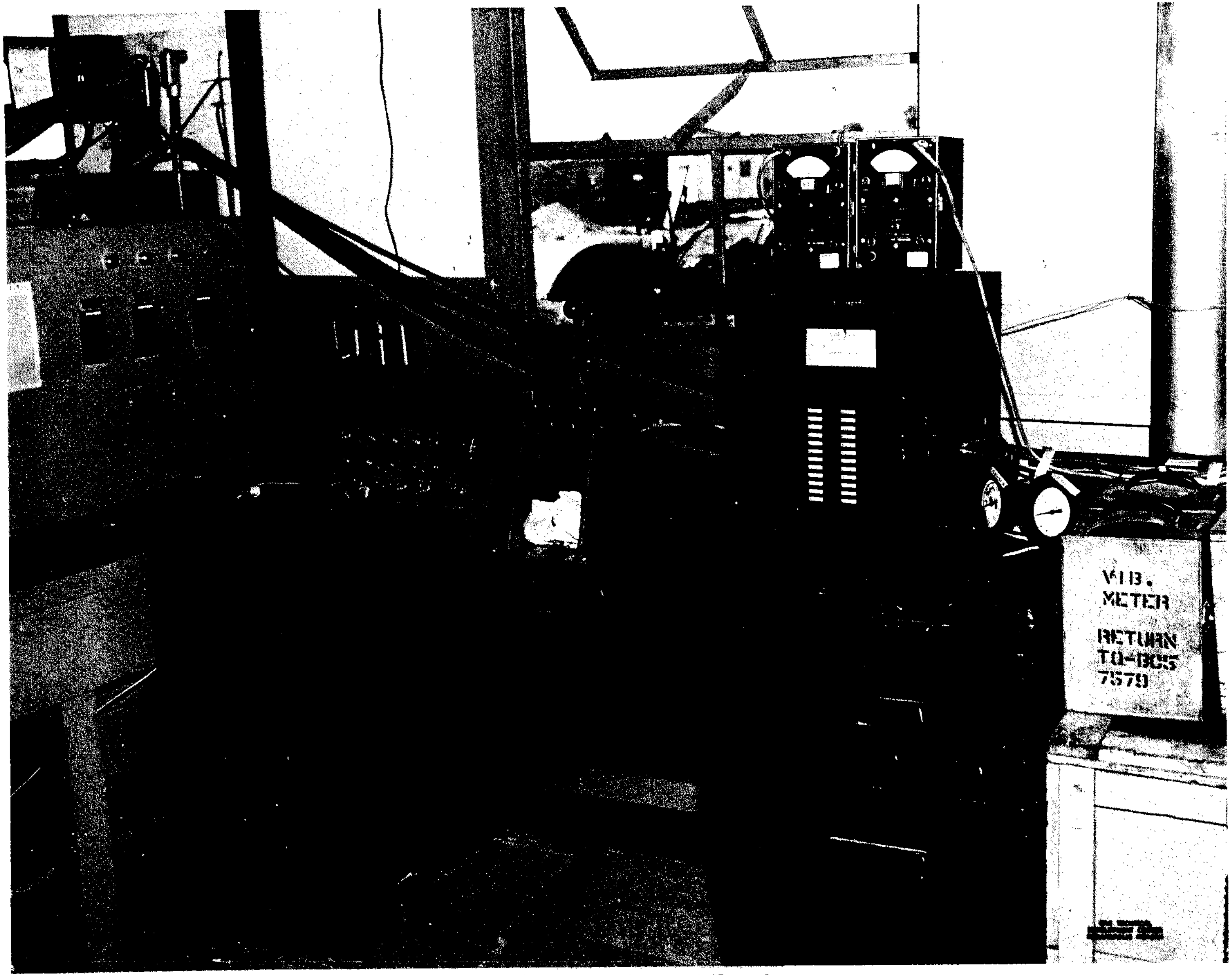

Fig. 4 Engine Control Panel

Fig. 5 Bird Carcass Projectile

Fig. 6 Test No. 3 - 8/16/56 - Projectile Velocity 330 mph

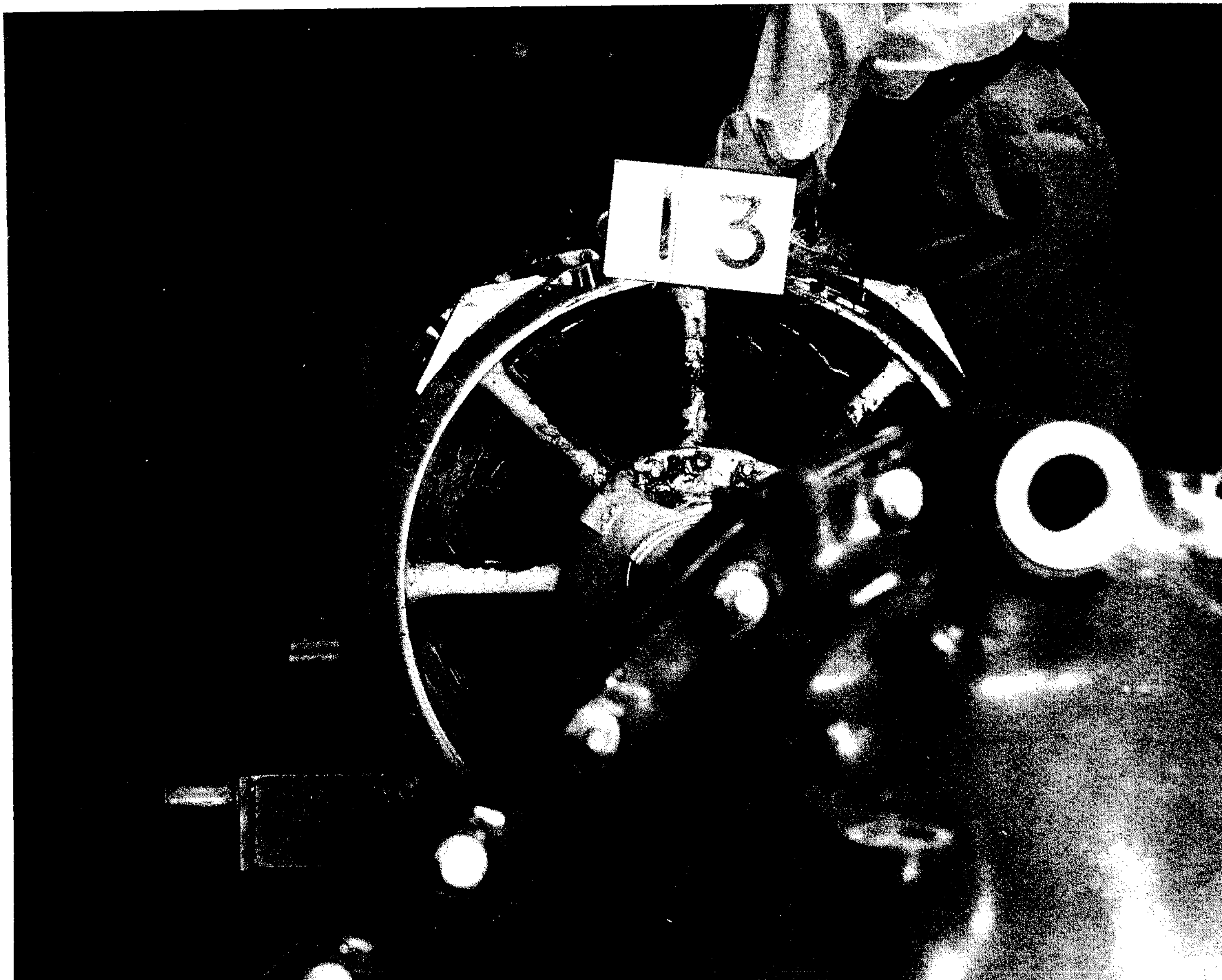

Fig. 7 Test No. 13 - 8/28/56 - Projectile Velocity 335 mph

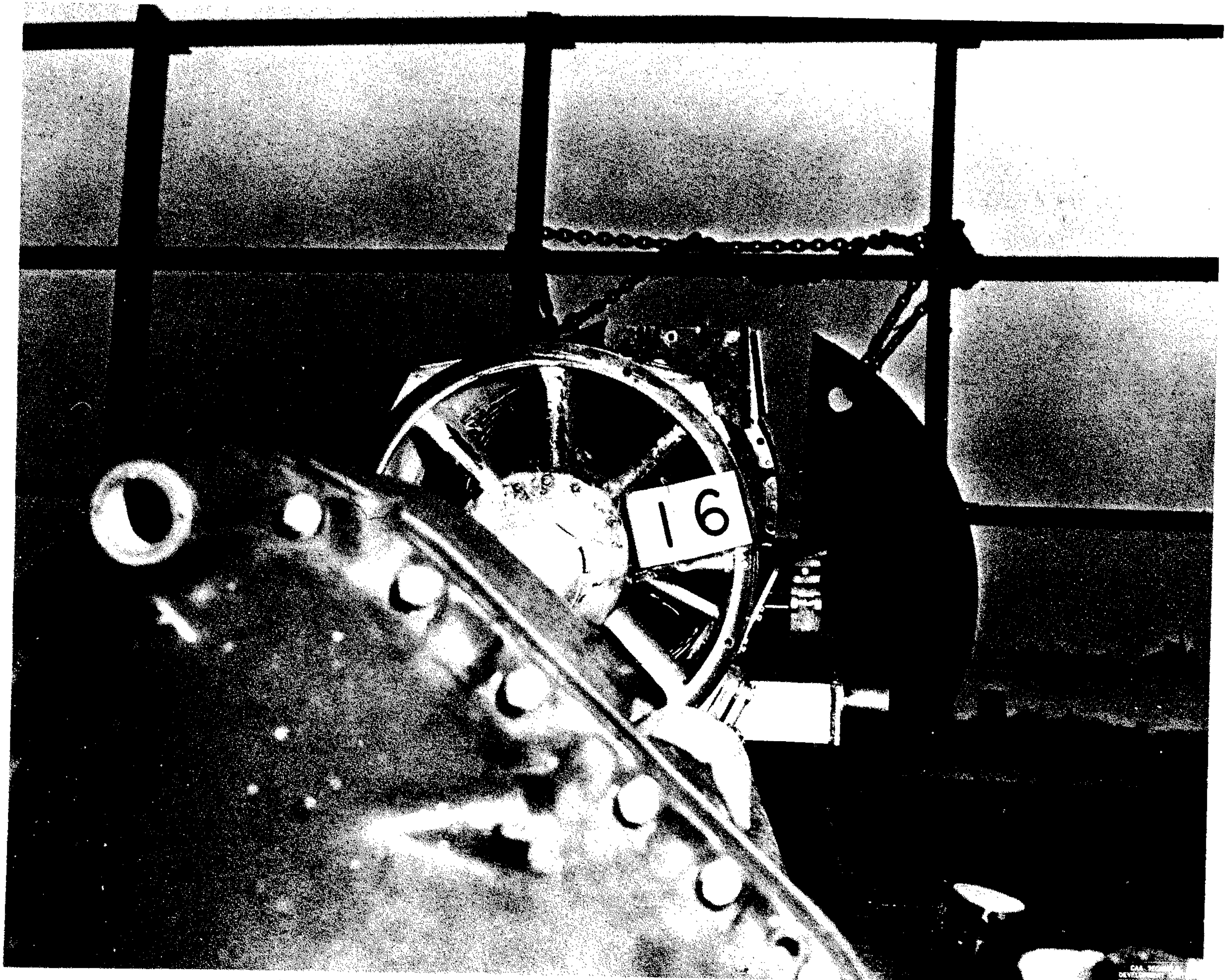

Fig. 8 Test No. 16 - 8/29/56 - Projectile Velocity 380 mph

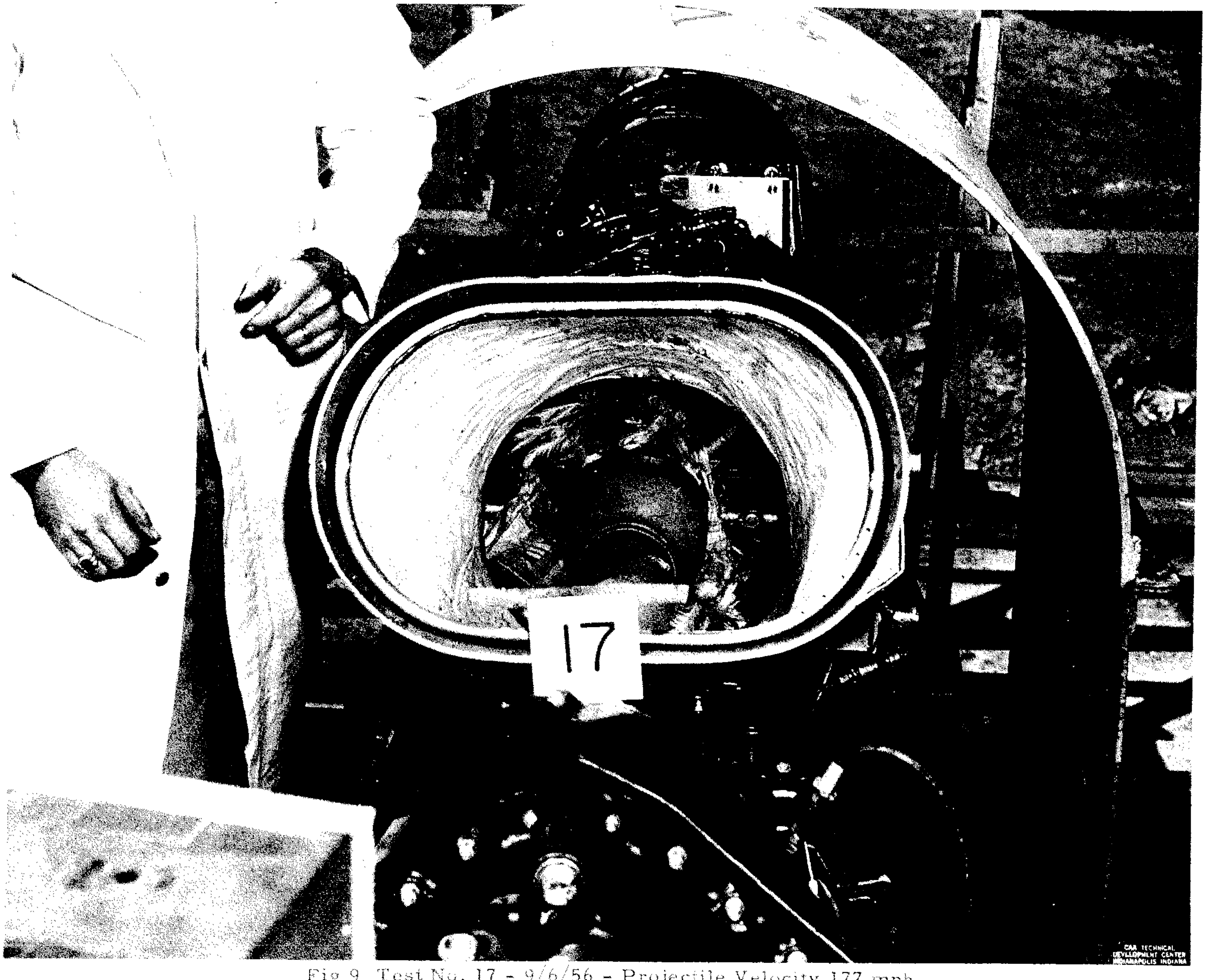

Fig 9 Test No. 17 - 9/6/56 - Projectile Velocity 177 mph

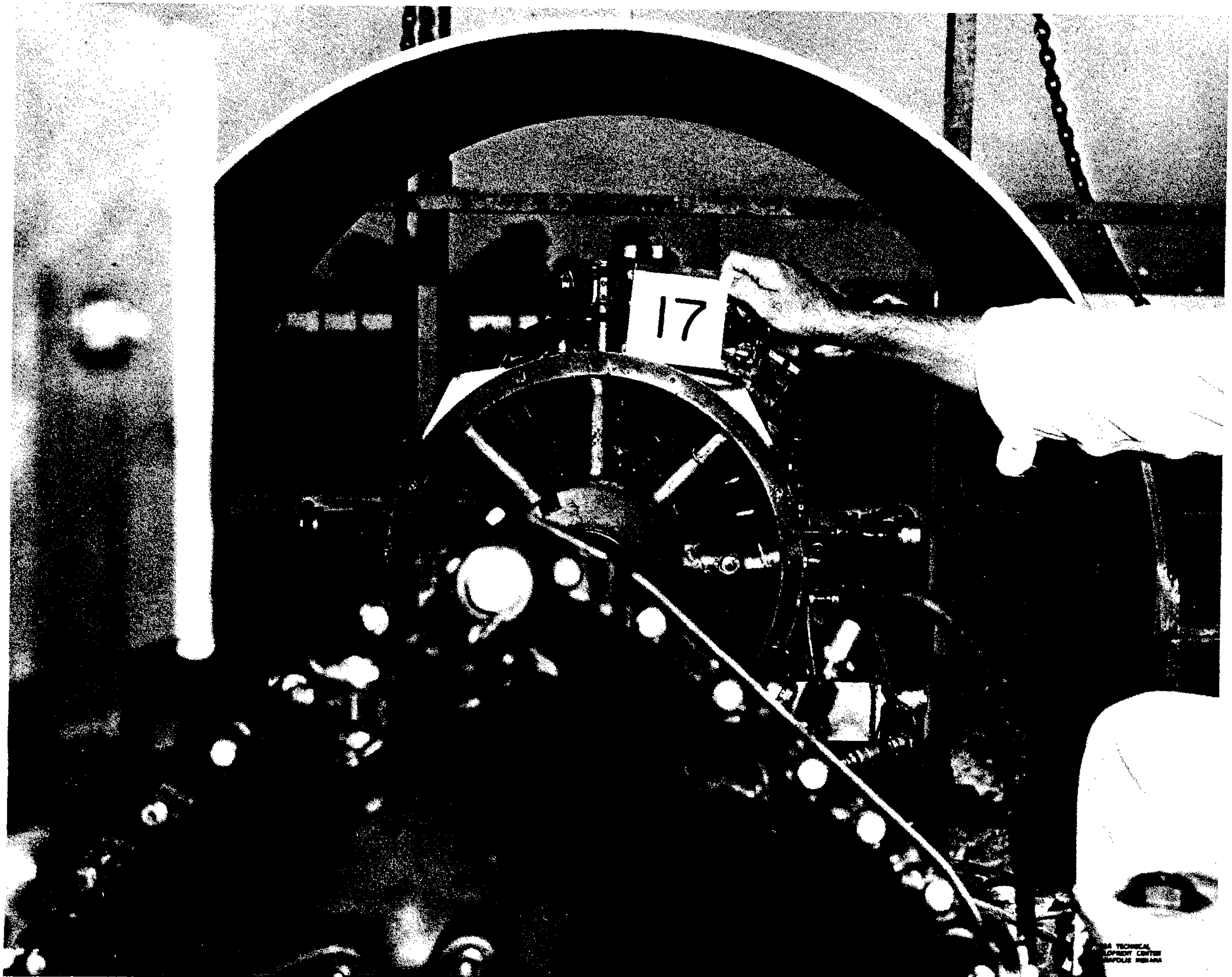

Fig. 10 Test No. 17 - 9/6/56 - Projectile Velocity 177 mph

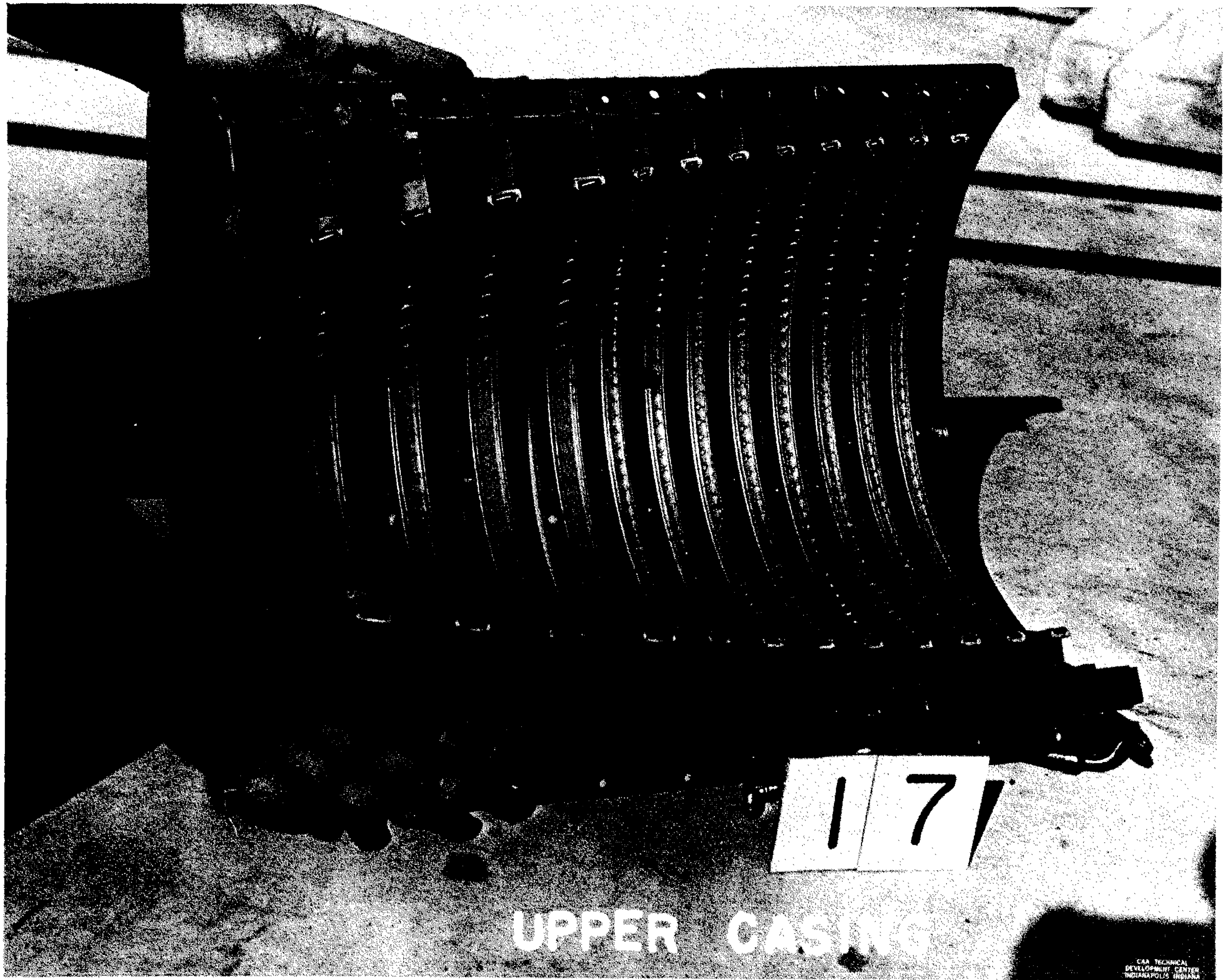

Fig. 11 Test No. 17 - 9/6/56 - Projectile Velocity 177 mph

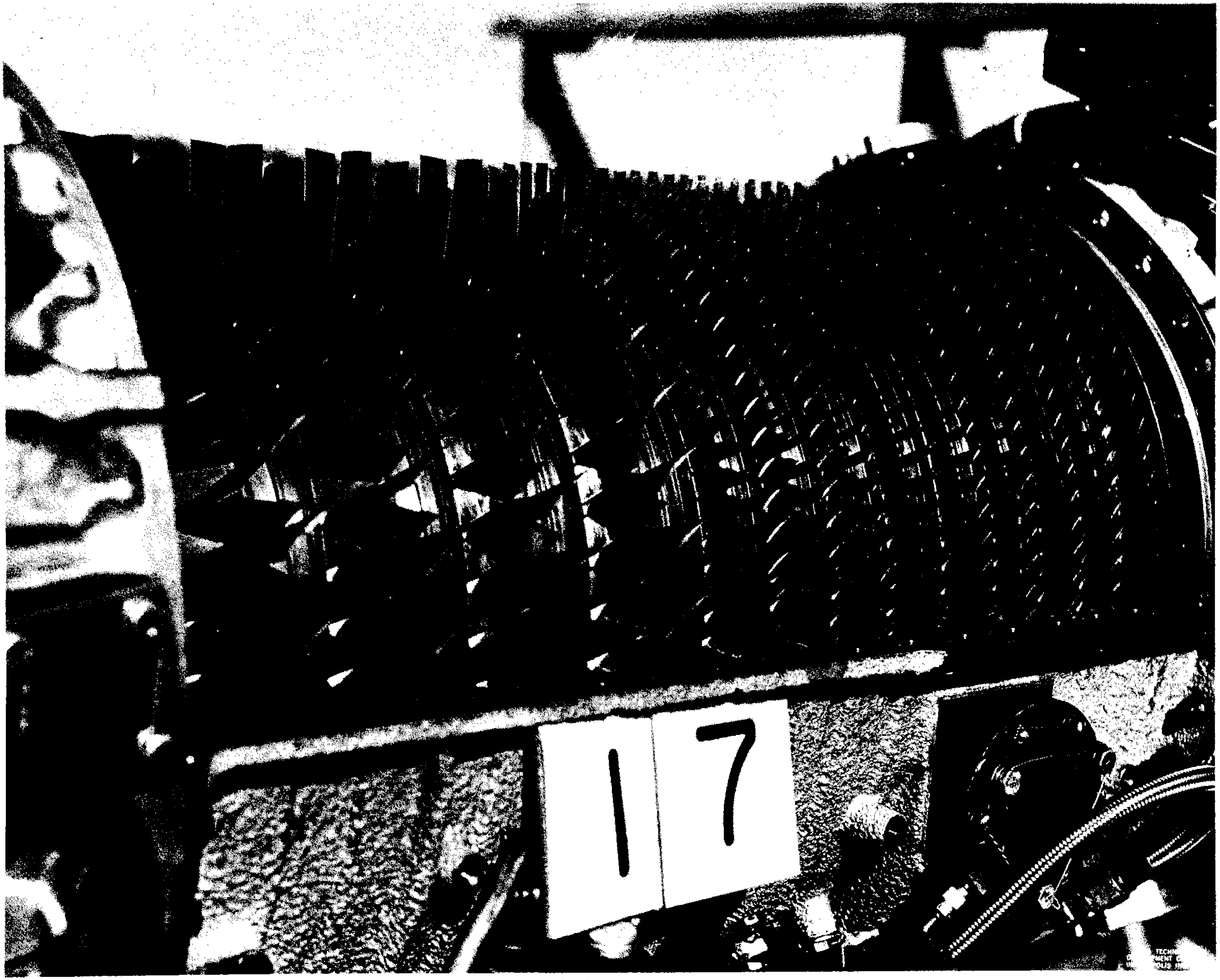

Fig. 12 Test No. 17 - 9/6/56 - Projectile Velocity 177 mph

Fig. 13 Test No. 18 - 9/13/56 - Projectile Velocity 213 mph

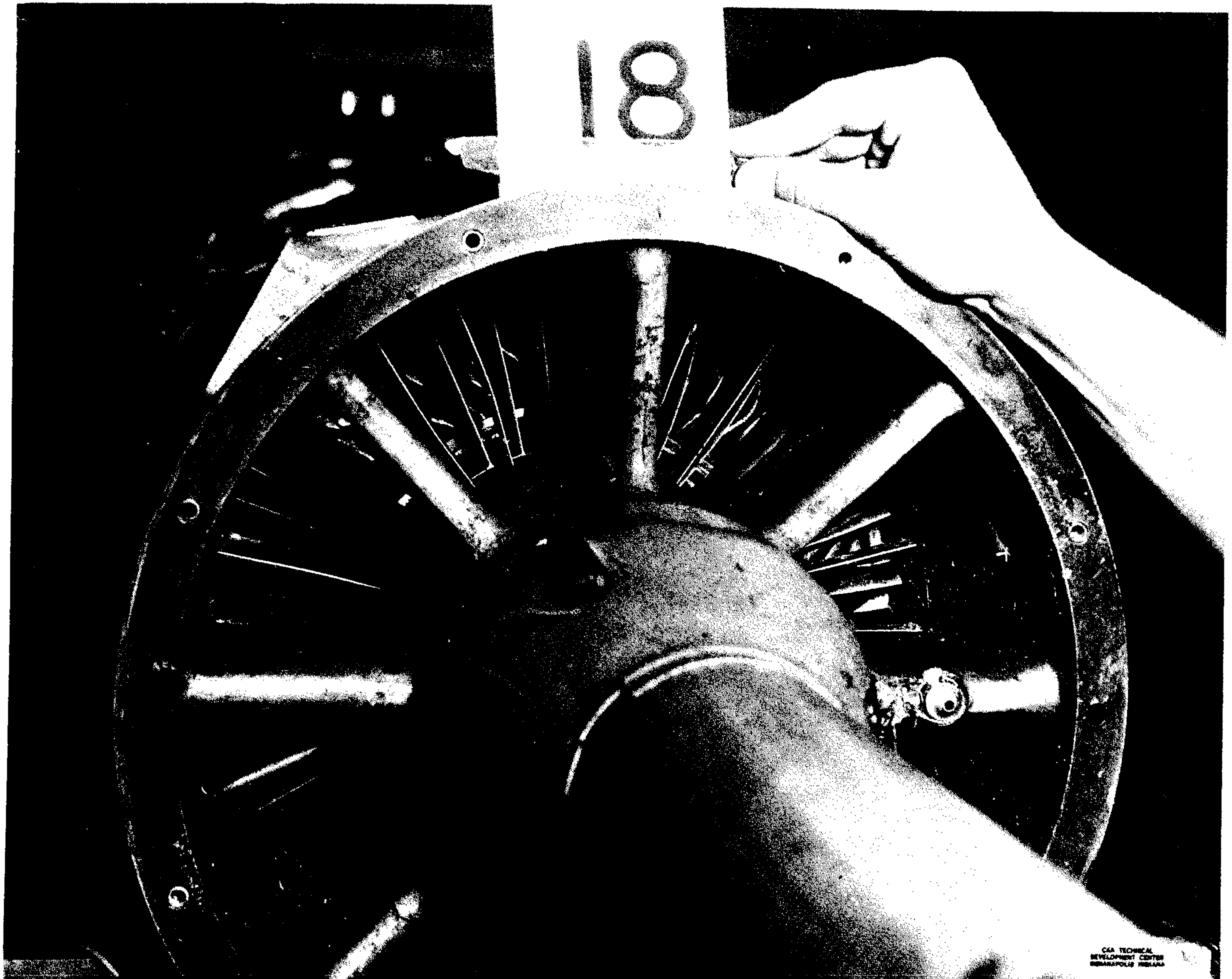

Fig. 14 Test No. 18 - 9/13/56 - Projectile Velocity 213 mph

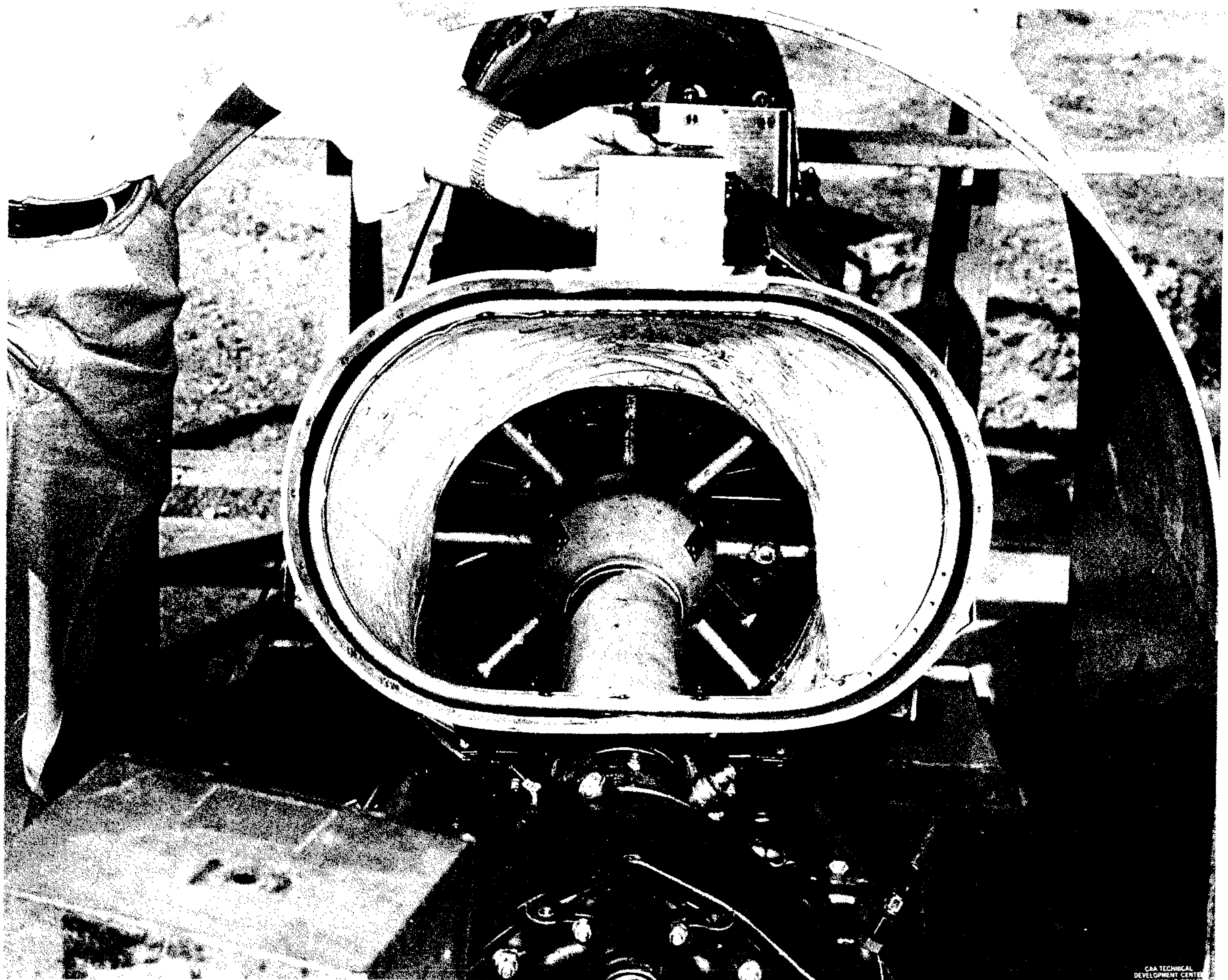

Fig. 15 Test No. 19 - 10/11/56 - Projectile Velocity 150 mph

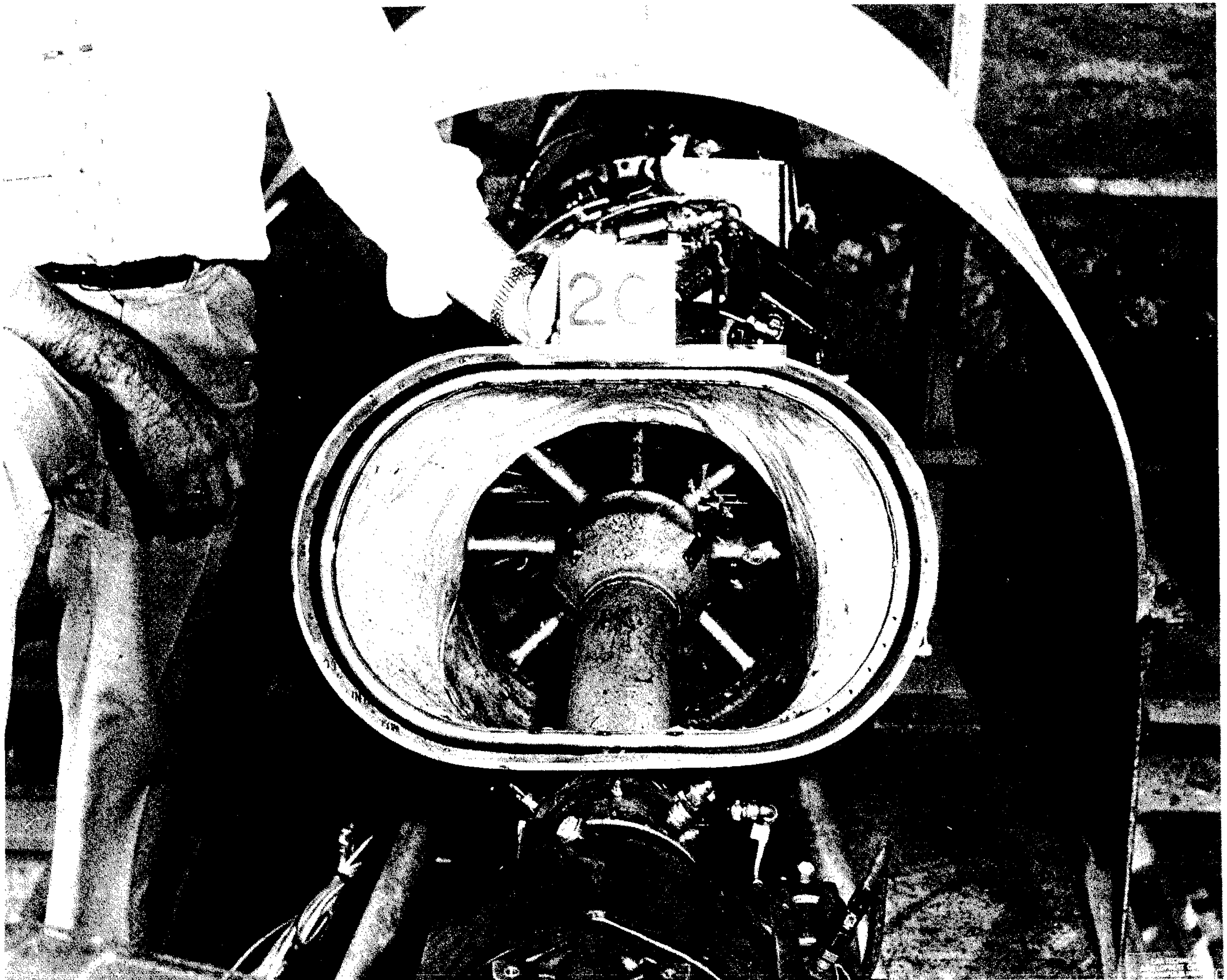

Fig. 16 Test No. 20 - 10/11/56 - Projectile Velocity 166 mph

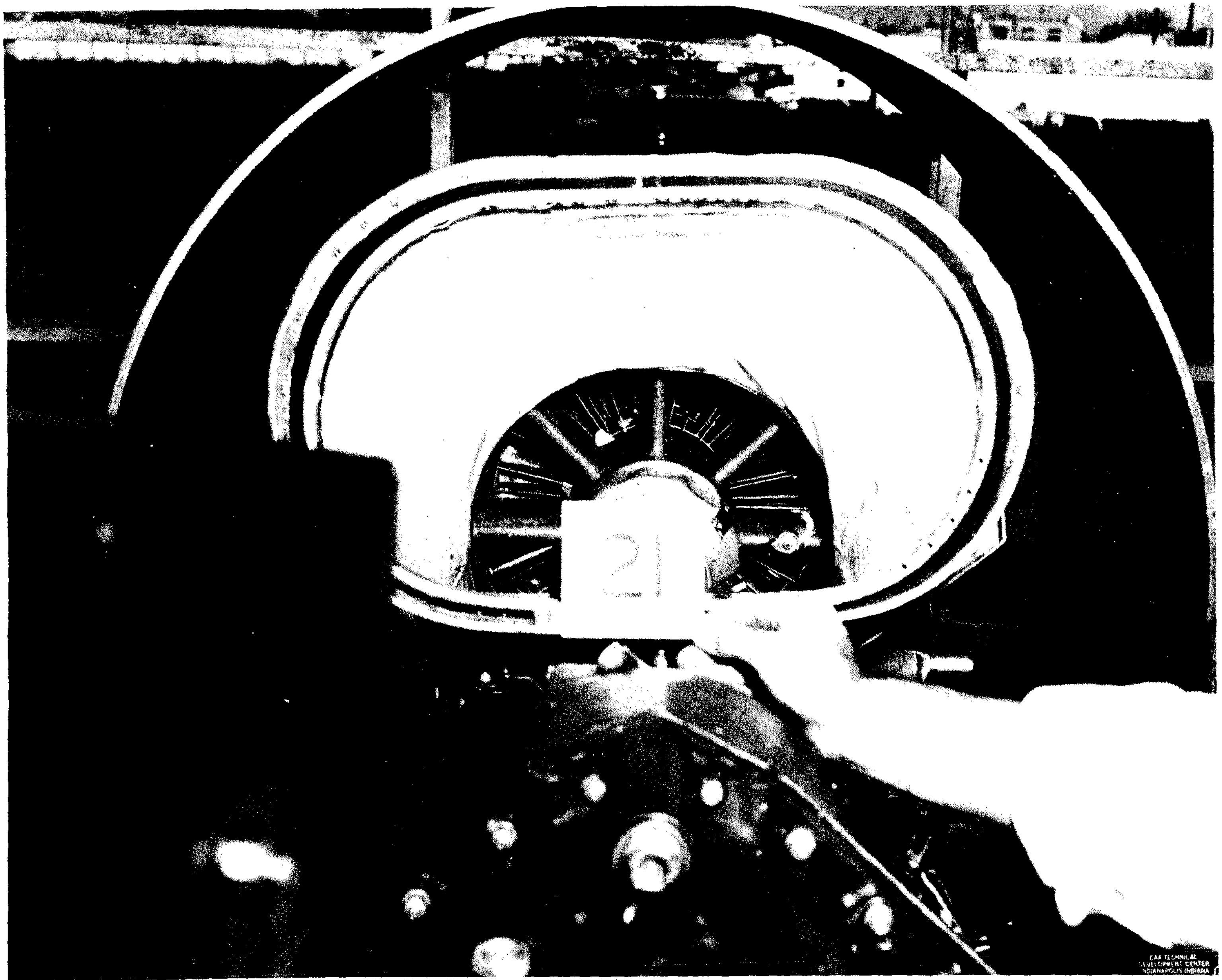

Fig. 17 Test No. 21 - 10/16/56 - Projectile Velocity 143 mph

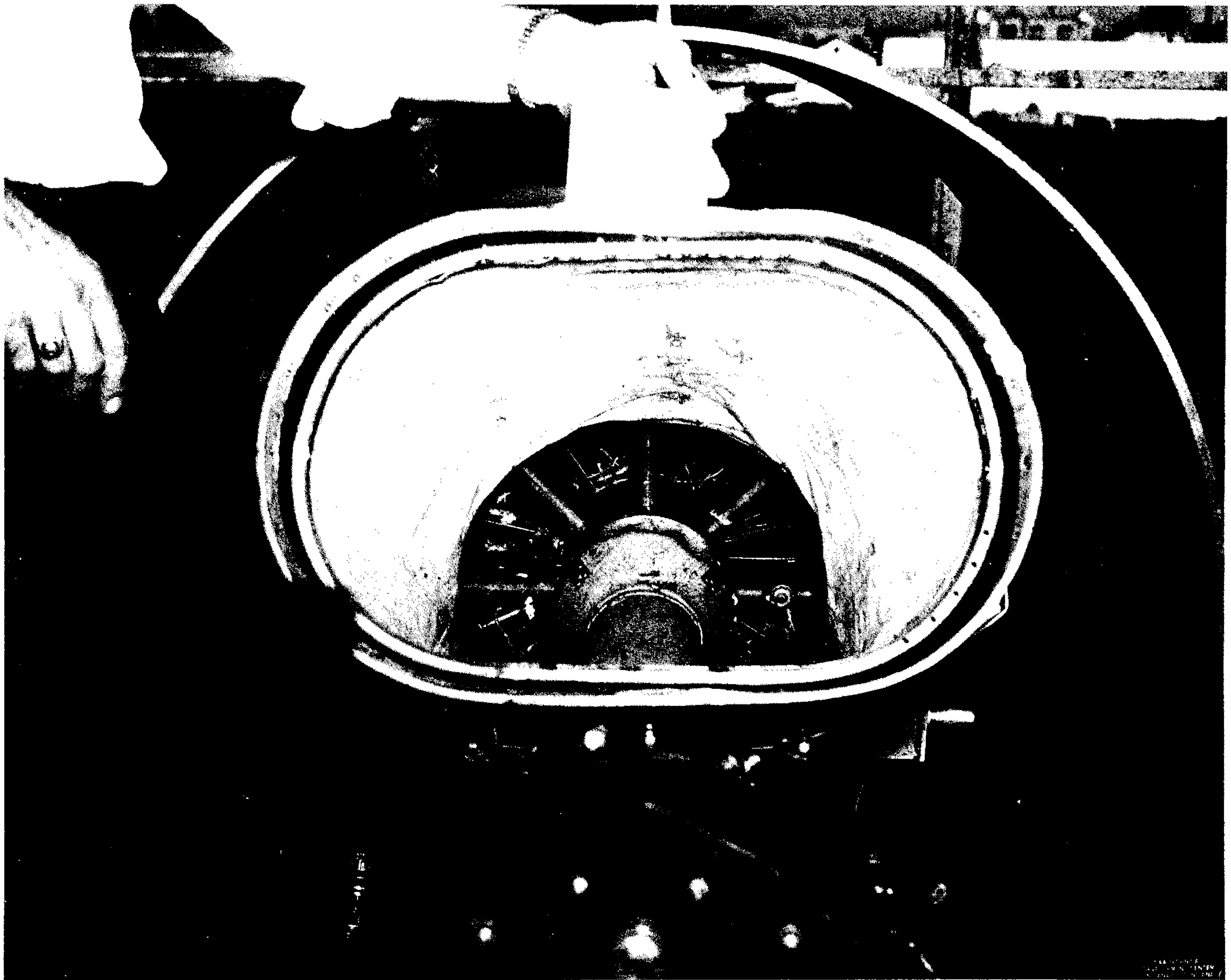

Fig. 18 Test No. 22 - 10/16/56 - Projectile Velocity 184 mph

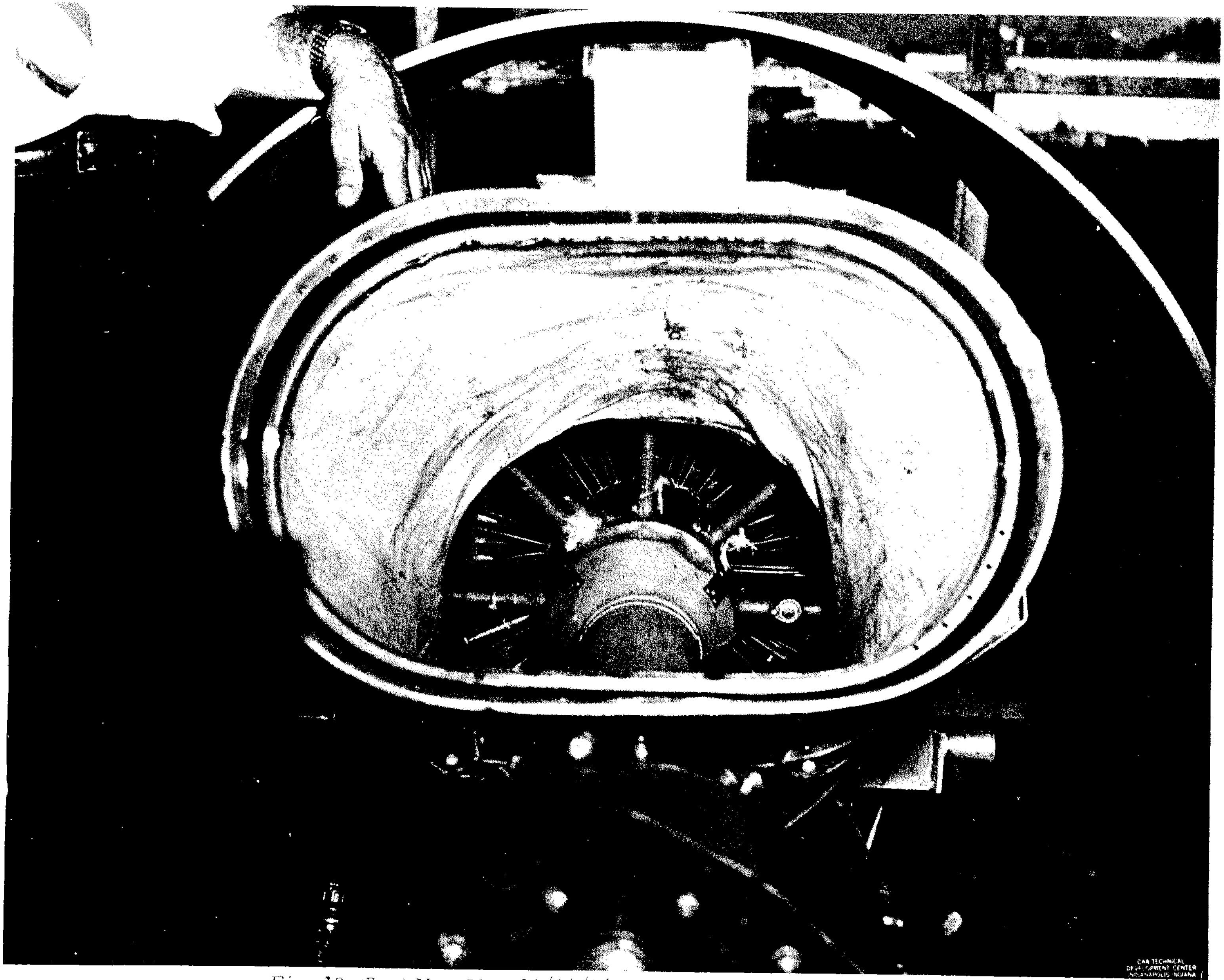

Fig. 19 Test No. 23 - 10/16/56 - Projectile Velocity 162 mph

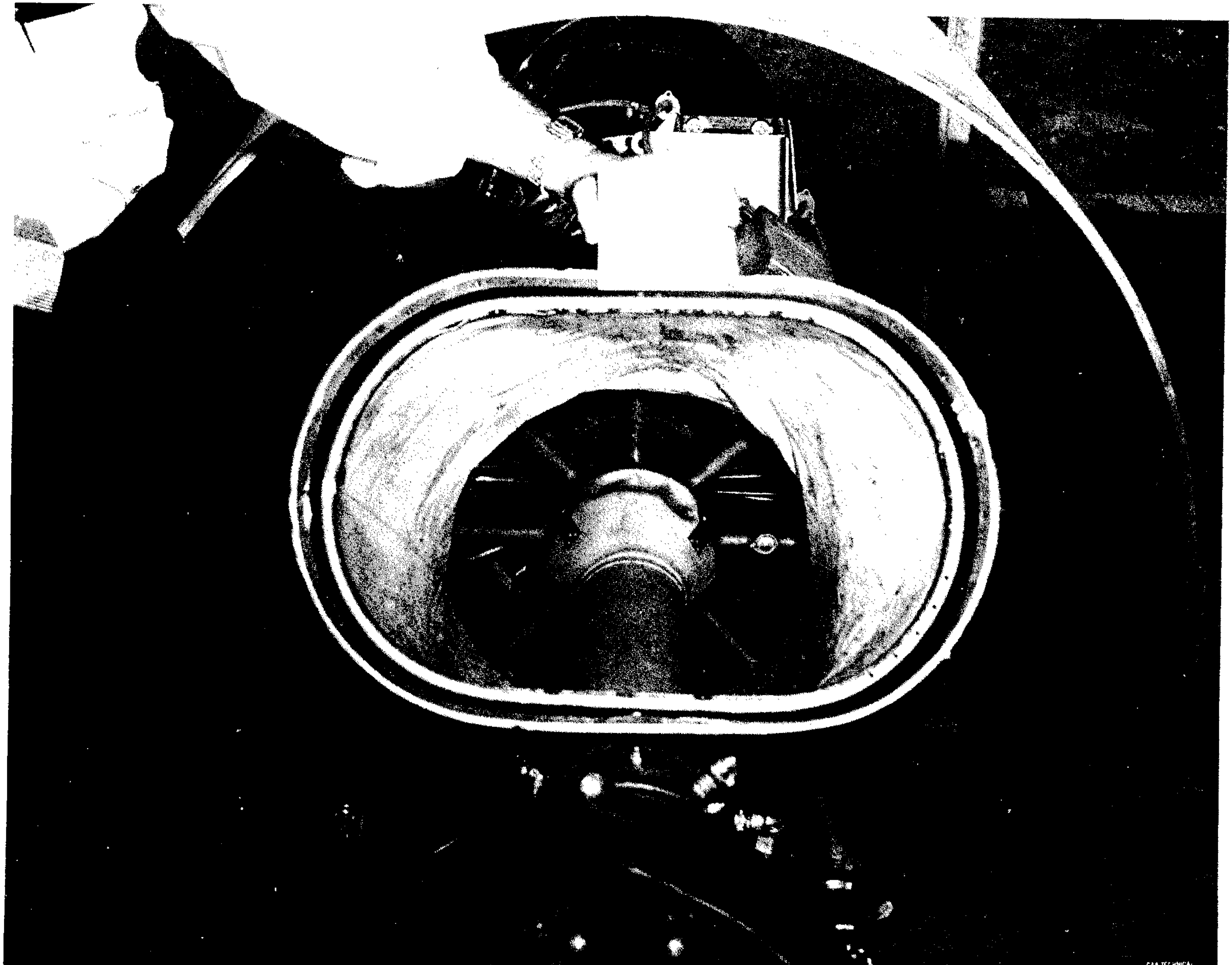

Fig. 20 Test No. 24 - 10/16/56 - Projectile Velocity 212 mph

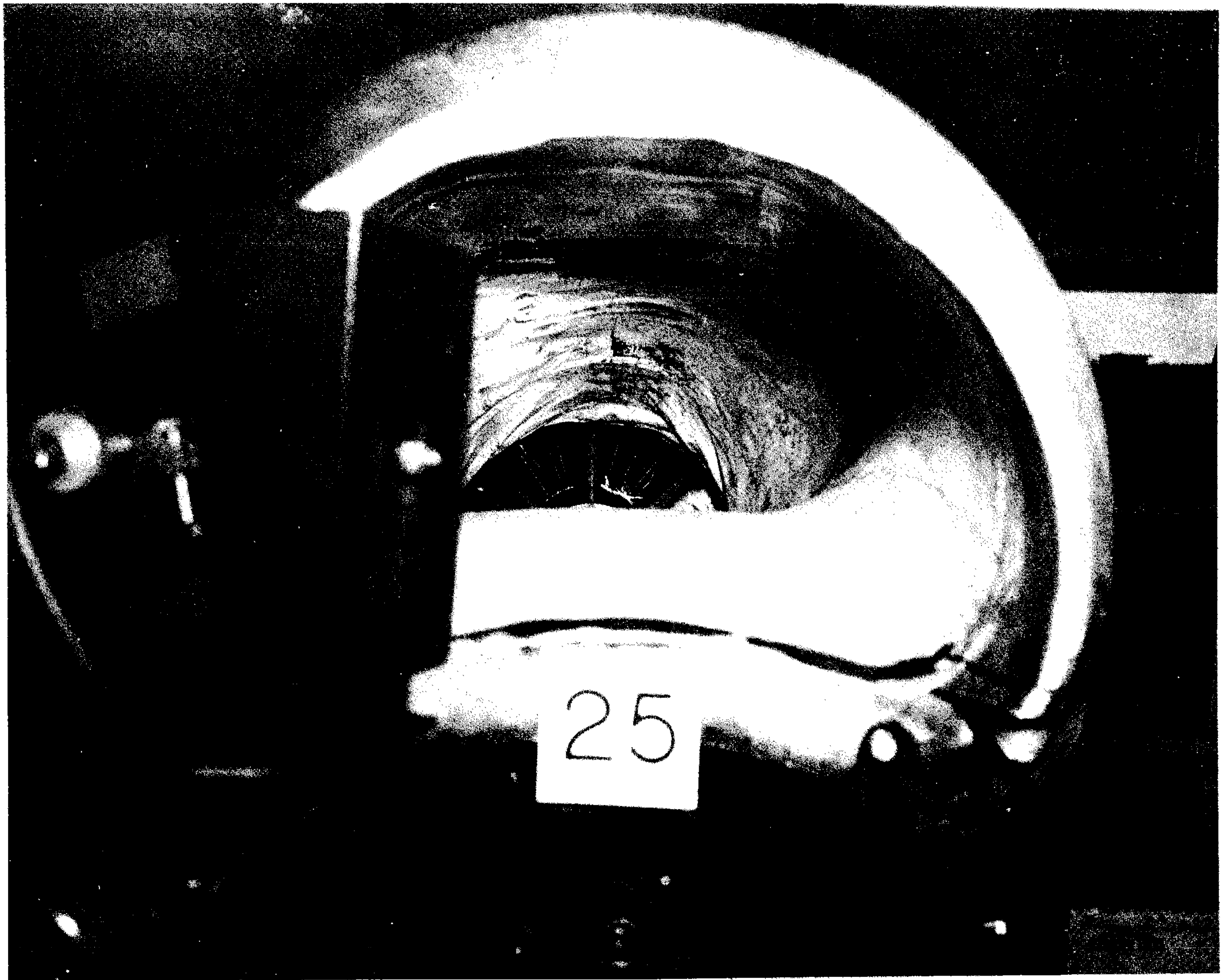

Fig. 21 Test No. 25 - 10/17/56 - Projectile Velocity 35 mph

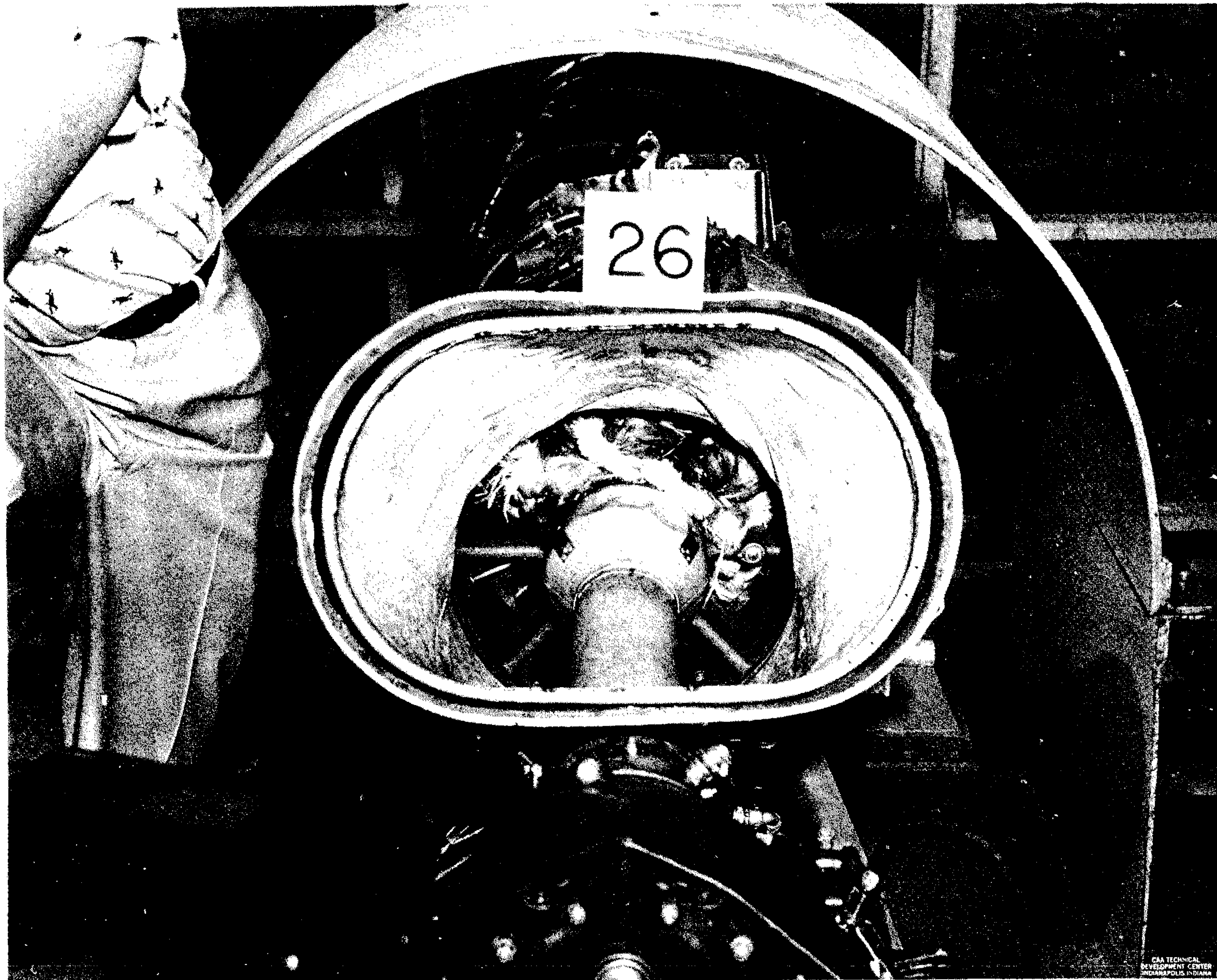

Fig. 22 Test No. 26 - 10/17/56 - Projectile Velocity 103 mph

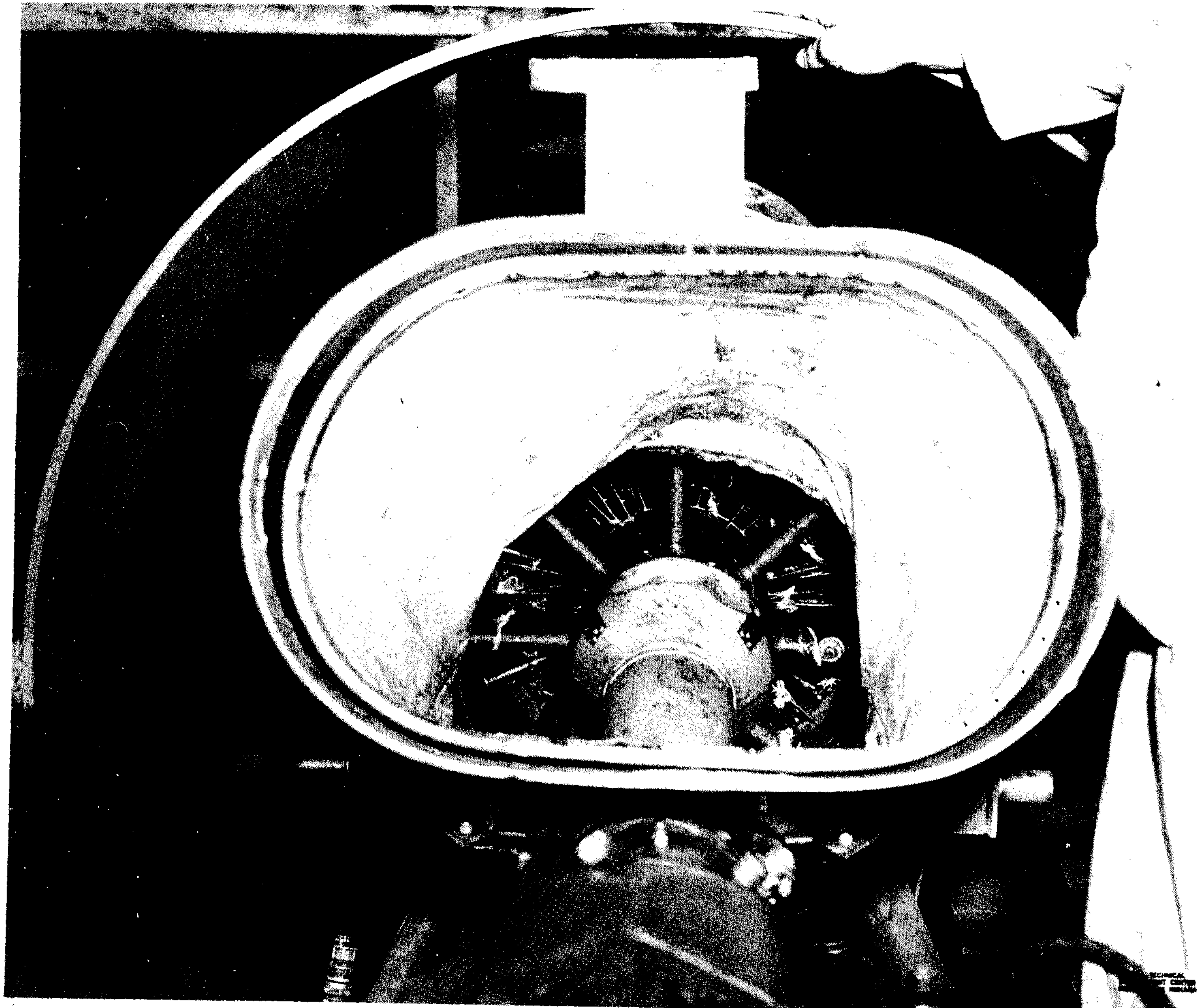

Fig. 23 Test No. 27 - 10/17/56 - Projectile Velocity 289 mph