REDUCTION OF RADAR CROSS SECTION OF LARGE HIGH ALTITUDE AIRCRAFT

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REDUCTION OF RADAR CROSS SECTION OF LARGE HIGH ALTITUDE AIRCRAFT

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This report is a summary of some of the work done by the Advanced Development Projects Division (ADP) of Lockheed Aircraft Corporation (known more widely as the Skunk Works) in reducing the radar cross section of various aircraft designs during the period 1956 to 1974.

The work was sponsored by the U. S. Government under the cognizance of Mr. R. M. Bissell.

The ADP activities were supervised by the writer. A number of consulting groups played important parts in the overall program - such as Lincoln Laboratories, Scientific Engineering Company, Inc. (SEI), Pratt & Whitney Aircraft Corporation, Edgerton, Germeshausen and Grier, Inc. (EG&G), Westinghouse, General Electric and a number of individuals from universities and industry.

The general activity was instigated in the time period when the Lockheed U-2 entered service in 1956 making numerous overflights of the Russian land mass. The Soviet reaction to these flights led them to accelerate their developments in radar (Tall King, Fan Song, etc.) and missiles, leading to the SA-2 type, which finally shot down Francis Gary Powers on May 1, 1960.

During the period 1956 through 1960, ADP undertook many studies of various aircraft designs intended to reduce the radar cross section as well as to improve the cruising speed, altitude, and range of reconnaissance aircraft. Shape factors lead to consideration of all forms of aircraft including flying saucers, which fundamentally have a low radar reflection from low viewing angles. Materials, such as rubber, plastics, inflated Mylar, carbon loaded honeycomb, etc., were used to configure many different designs. After the Powers incident, work on reducing the vulnerability of the U-2 accelerated to meet the threat. Electronic countermeasures - ECM - for warning the pilot against radar sightings, for jamming missile guidance systems, and aircraft gunnery radars were given the highest possible priority. (ECM developments and reduction of high altitude optical visibility will not be reported herein.)

The basic radar frequencies used in evaluation of the aircraft radar cross section were 70, 170, 2850, and 5000 megahertz with each frequency varied from its normal value given by plus or minus 5% to account for actual frequency variations which might be encountered in the field. The lower frequencies were those of the early warning systems, and the higher ones were actually both ground based and airborne radars used by fighter aircraft. It was necessary to consider the wide range of frequencies so as not to be misled by the fact that its relatively easy to reduce cross sections of aircraft at a single specific narrow band frequency.

Summary

By combining the effect of shapes, resistively loaded plastics and other design features, the radar cross section of aircraft such as the SR-71 was reduced very significantly over a wide range of radar frequencies, beam polarizations and look angles, compared to normal design practices. With all these factors, however, it was not possible to create an aircraft invisible to early warning or missile guidance radars, but in combination with high speed, high altitude, maneuvering and electronic countermeasures, a very high degree of survivability has been obtained in service.

The very difficult problems of reducing the return of the air inlet on the engines, from canopies, camera windows, radomes, and antenna installations were satisfactorily achieved after thousands of tests both at model and full scale. Test techniques were successfully developed for both ground and flight conditions, as were manufacturing methods for producing high temperature plastics, loaded foam, and structural honeycomb components.

The Effect of Basic Shape

In order to evaluate the effect of overall shape on radar cross section, tests were run over a 10 year period of many different aircraft designs. These were run in a small radar anechoic chamber having dimensions of 12' x 12' x 30' and later in the new large ADP anechoic chamber shown in Figures 7, 8, 9 and 10 which is much larger. Some tests were run on an outside radar range located on a dry lake, but in general, most of the early tests were run in the small box. Elementary shapes were evaluated, such as disks of different contours, streamline shapes, and various bodies designed for producing low radar sections without consideration of their aerodynamic feasibility as aircraft. Fundamentally, a shape similar to flying saucers with a sharp edge and no protuberances has a very low radar cross section without any anti-radar treatment at all, particularly against vertical polarization of the radar beam when viewed at small angles of incidence. Attempts were made simultaneously to develop power plant installations and control systems which would make some of the low radar cross section objects fly satisfactorily.

A substantial amount of effort went into development of all plastic designs, inflated Mylar and rubber aircraft and combinations thereof. Some interesting results were obtained in these tests. It was found for instance, that when the plastic parts, such as those that might be designed in wing beams, or heavy structural rings exceeded 1/4 or 1/2 inch in thickness, these members might just as well be metal. An unexpected result showed up in one model (which used very thin plastic for wing panels) which proved to be totally useless in the fuel tank region. A vibrating tank created a strong radar return from the surface of the fuel itself. It became obvious also that if a plastic fuselage which would be transparent to radar was used, the radar beam saw the engine and its associate accessories, plumbing, et al, which then provided hundreds of corner reflections and provided large radar returns. Figures 11 through 18 show a few of the models tested during this early evaluation at ADP. The net result of our tests on aircraft shapes leads the writer to conclude that the most desirable shape for an advanced, high altitude reconnaissance aircraft should have the following characteristics:

a. A wing of very low thickness ratio.

b. A cross section of the fuselage and engines blended into the wing with the shape of the engine nacelles and fuselage approaching a flying saucer as closely as possible!

c. The number of tail surfaces should be minimal and the vertical tails (if dual) tilted inward to reflect the radar returns off into space. These surfaces should be constructed of loaded plastic honeycomb combined with surface treatments.

d. Both the engine air inlet and exhaust outlets would require extensive development and some unique approaches would be required to reduce the radar cross section from fore and aft viewing angles.

e. There must be no external antennas or other such protuberances, and radomes for such items as side looking radar must be given very special attention. The ability of the installed radar to look out of the fuselage at the same time not allowing a search radar to look in, is required.

f. Steps would have to be taken to reduce the radar cross section of a man's head for instance, which alone has a return of something like two-tenths of a square meter at S-band. Flying helmets and canopies can be treated to reduce this effect fortunately.

In order to evaluate full scale aircraft as well as model configurations at different radar frequencies, a radar test range was developed on a dry lake in the desert. This range provided for a one mile separation between model and the radar test equipment with intermediate mountings provided for different scale models. ADP designed the large rotating pedestal (Figures 19 and 20) which was able to raise a flyable SR-71 over 60 feet in the air with the ability to tilt the model and rotate it in the horizontal plane. Edgerton,Germeshausen and Grier, Incorporated installed the radars used for this testing, as well as the test equipment used, in collaboration with Lincoln Laboratories and Government personnel. The full scale model of the SR-71 was installed inverted to prevent ground reflection effects and the proper viewing angles could be obtained simulating the cruising angle of attack at the line of sight from an early warning radar approximately 300 miles away. This was the grazing angle of incidence for the radar beam with the Blackbird flying at its design altitude.

Dr. Frank Rodgers invented a device which we called the "railroad" which was a traveling corner reflector mounted on the rail alongside of the model. In essence, it was used to determine radar "hot spots" by determining the phase relationships from the corner reflector and the aircraft item, allowing one to draw two lines of bearing which would intersect at the source causing the high return. This was a most useful tool throughout the whole series of full scale tests.

Pressurized Mylar as well as neoprene bags were used to support a 1/8th scale model closer to the test center to study radar cross section at frequencies around 70 to 200 megahertz.

Considerable difficulty was encountered in the early tests because of returns from the post supporting the model and ground reflections. These were overcome by providing a retractable shield around the post which could go up and down with the model. The ground returns had to be controlled by placing carbon loaded hair pads on the ground under the model.

Figure List

Figure List

(Contd)

GOALS

1959

70 MC	$6\ m^2$
"S" BAND	$0.2\ m^2$

1960

170 MC	$1\ m^2$

REQUIREMENTS

1965

170 MC	$0.05\ m^2$
"C" BAND	$0.1\ m^2$
"S" BAND	$0.1\ m^2$

TOOLS-DEVELOPED TO DATE

INSTRUMENTATION

- MODEL RANGES
- FLIGHT TEST RANGE

TECHNIQUES

- SHAPE SELECTION
- HI TEMP PLASTICS & ABSORBERS
- FUEL ADDITIVES
- ELECTRON GUNS
- "IRON" PAINT

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Figure 6. Design A. R. Goals at Various Time Periods for ADP Programs

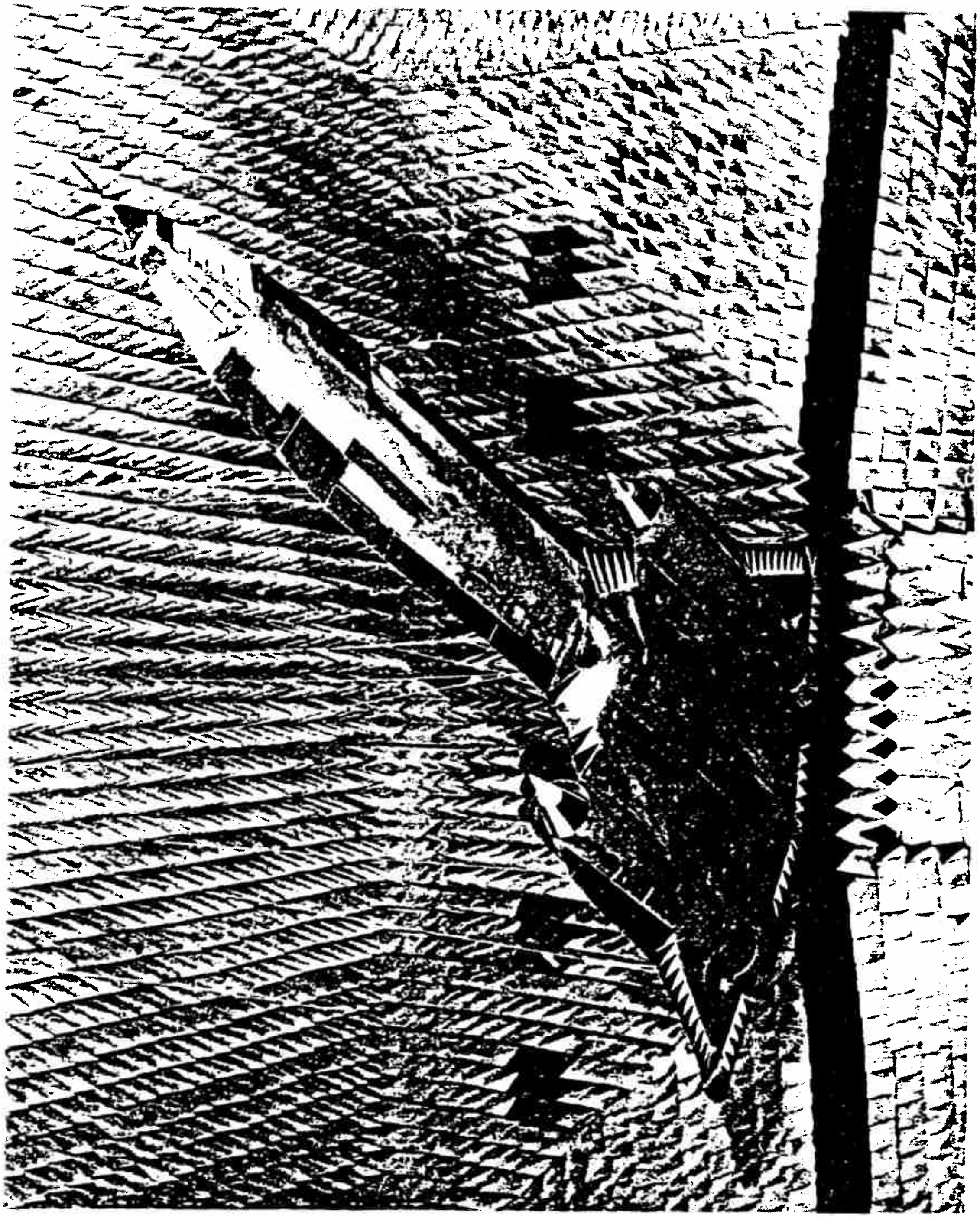

Figure 8. SR-71 Model in ADP Radar Anechoic Chamber

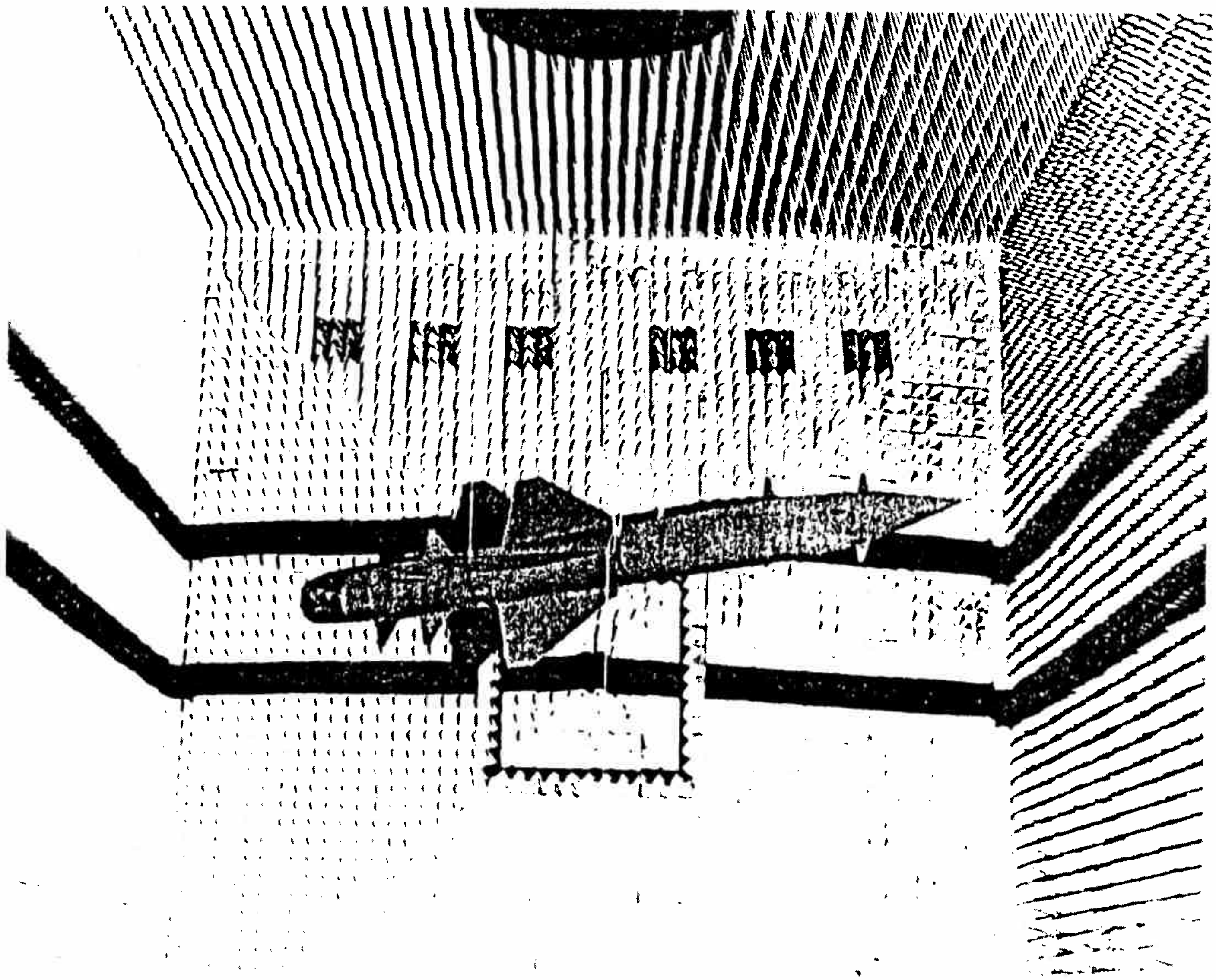

Figure 9. Full Scale SA-2 Missile Model in ADP Radar Anechoic Chamber

C885-1

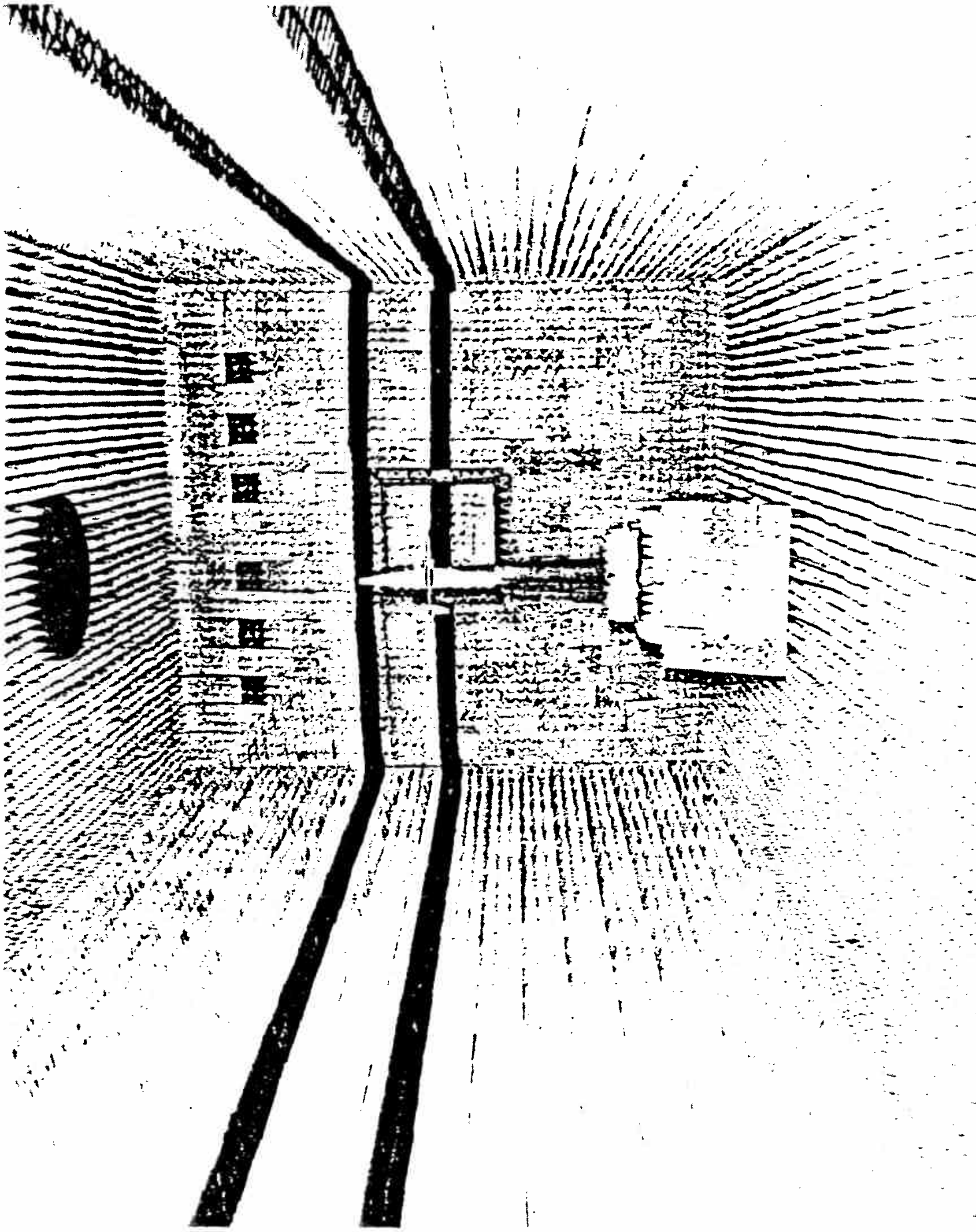

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Figure 10. U-2 Model in ADP Anechoic Chamber

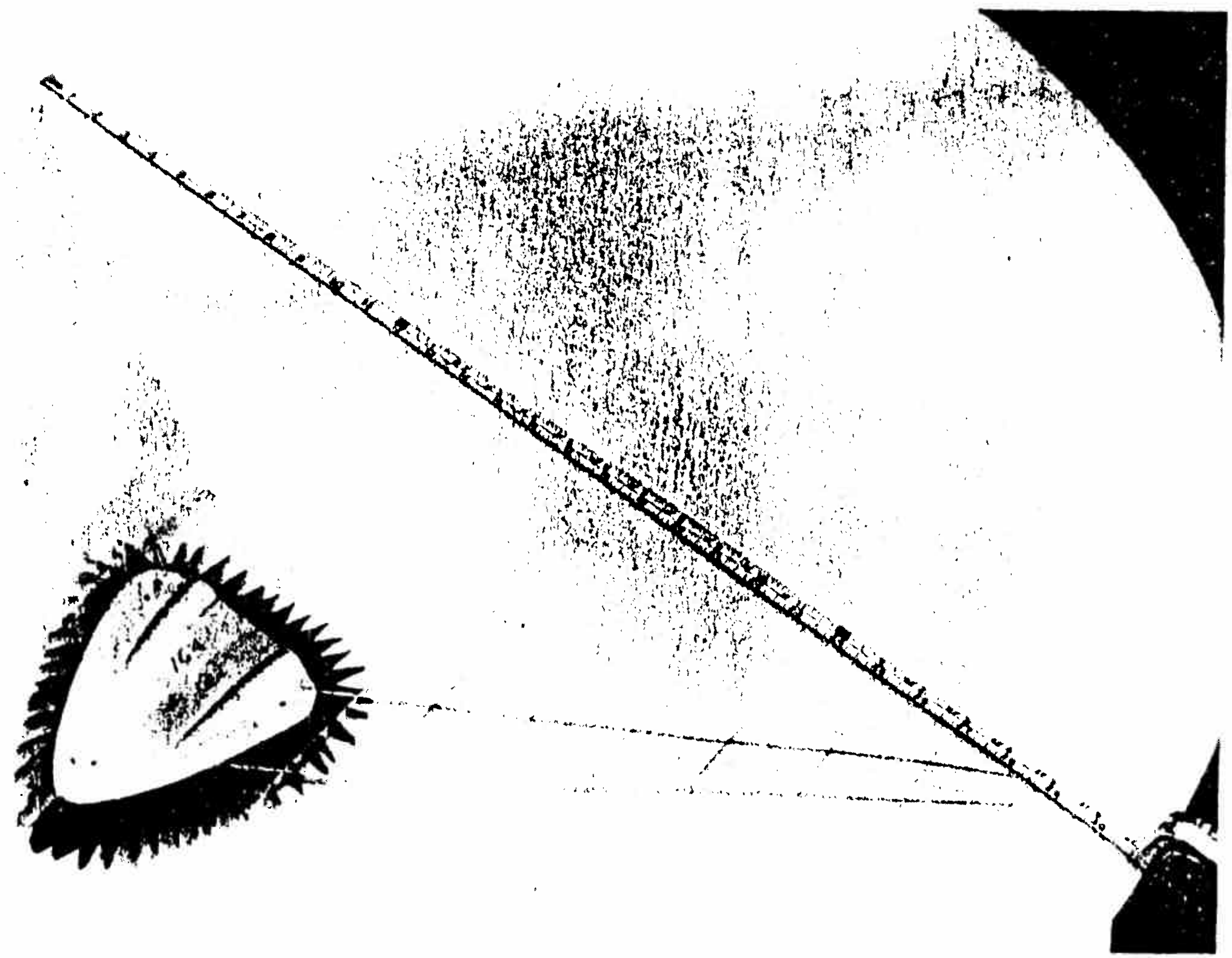

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Figure 11. Flying Saucer Model with all Plastic Wings Added

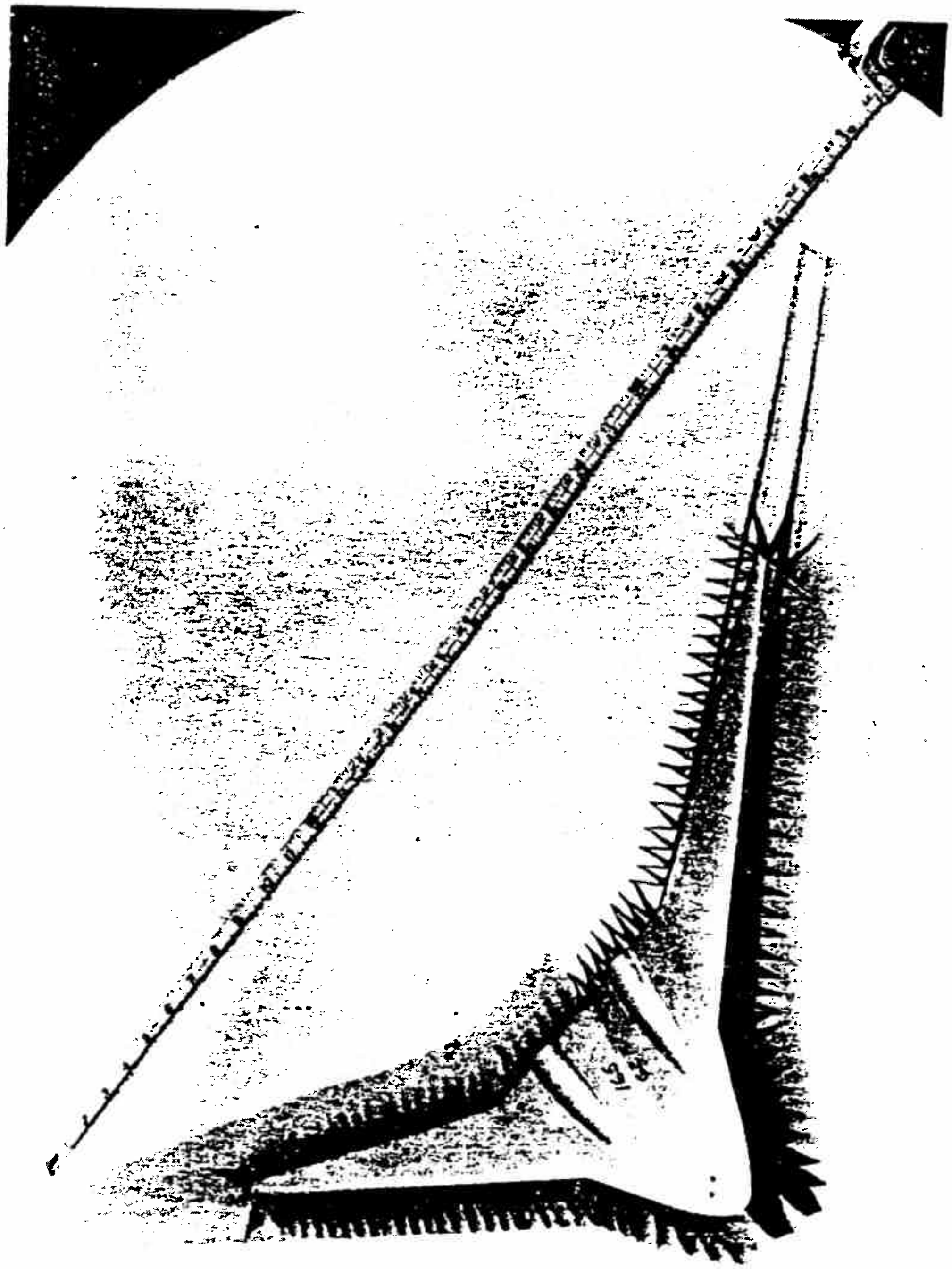

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Figure 12. Item 11 with Wing Anti-Radar Treatment Being Added

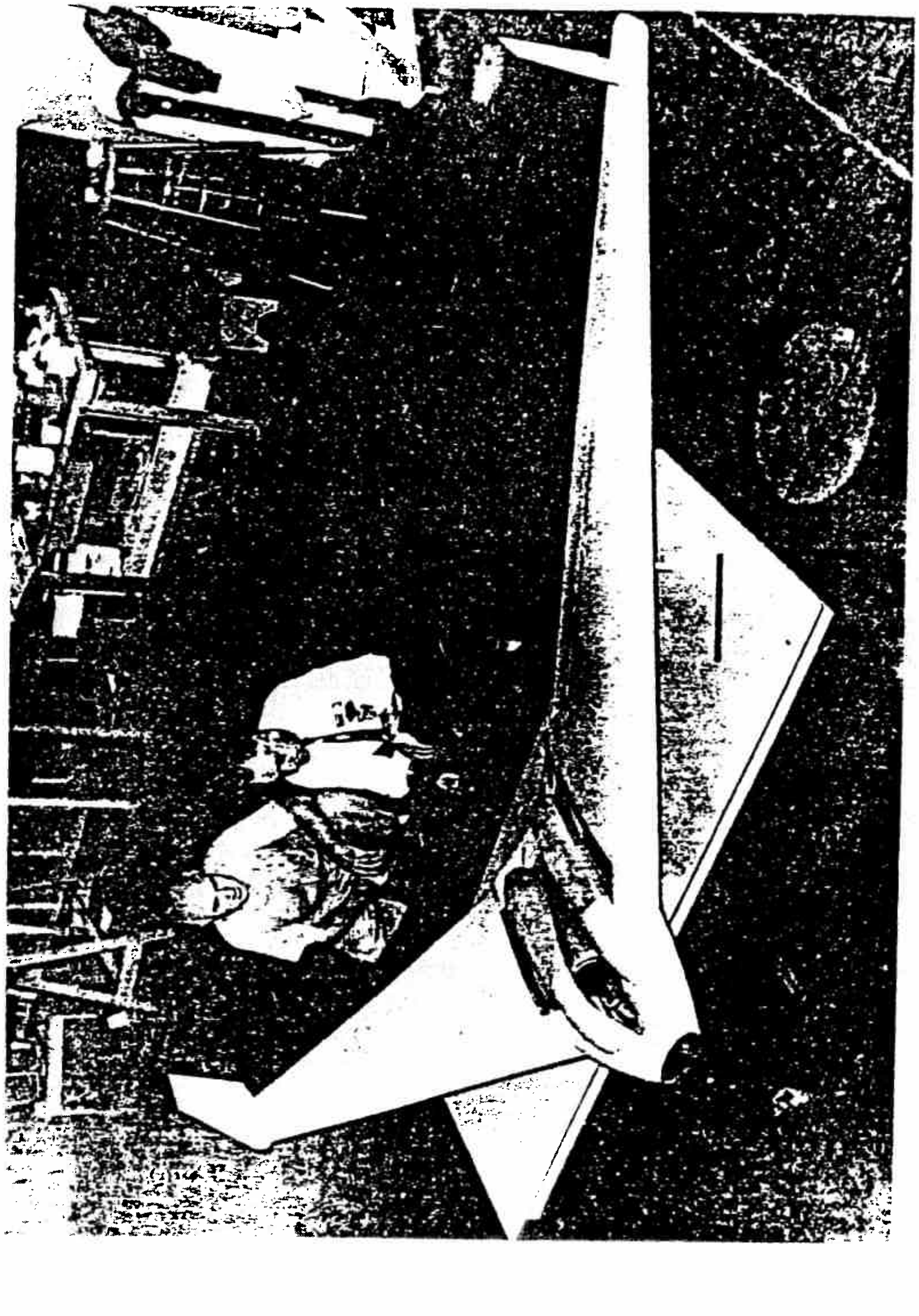

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Figure 13. Large Scale Flying Wing - A. R. Treated

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Figure 14. Various Aircraft Designs Tested

M31-9

Figure 15. Various Aircraft Designs Tested

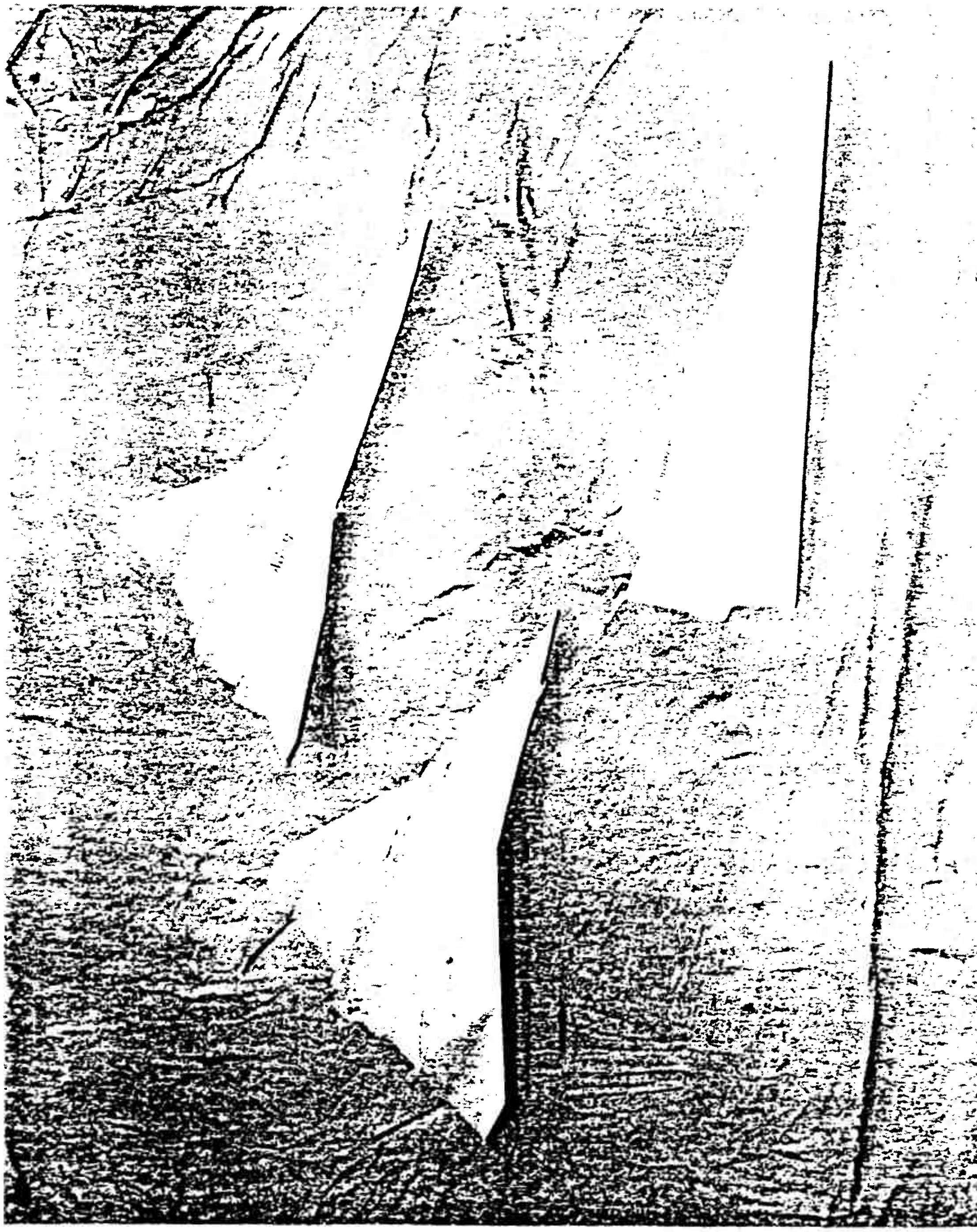

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Figure 16. Various Aircraft Designs Tested

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Figure 17. Various Aircraft Designs Tested

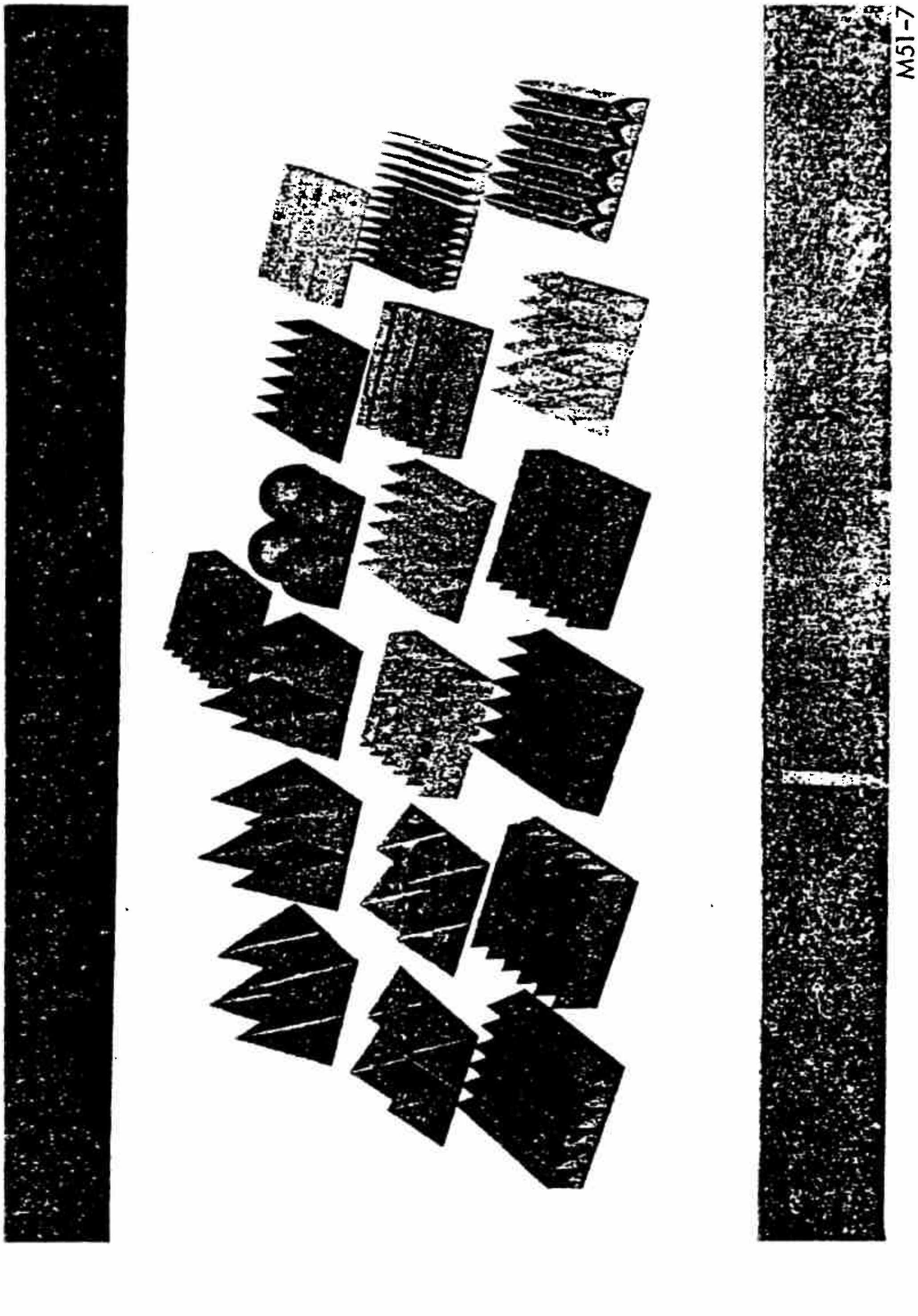

Figure 18. Loaded Plastic Absorber Developments

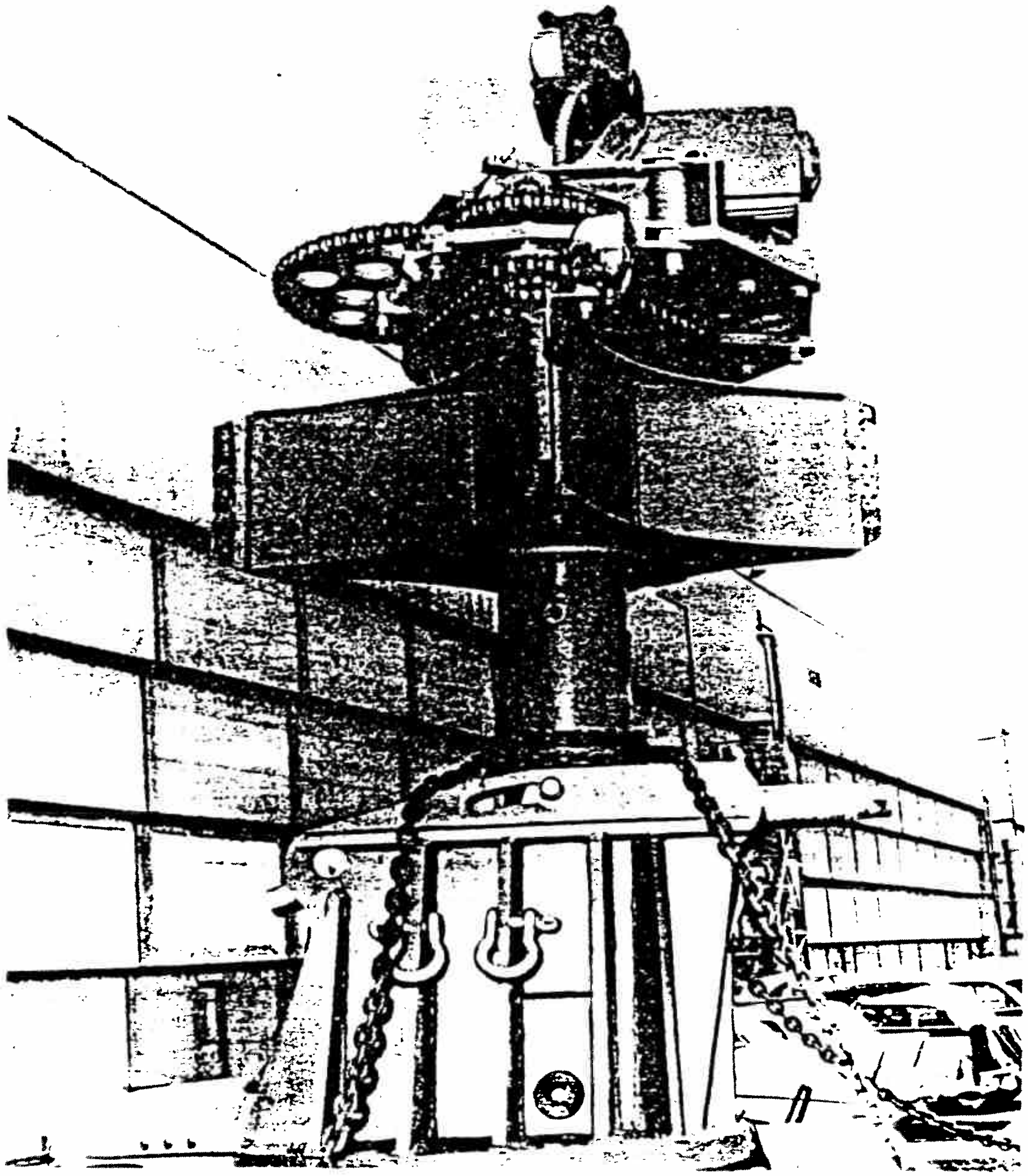

Figure 19. Mechanism for Large Pole Support to Hold Full Scale Aircraft 60 Feet Above Ground

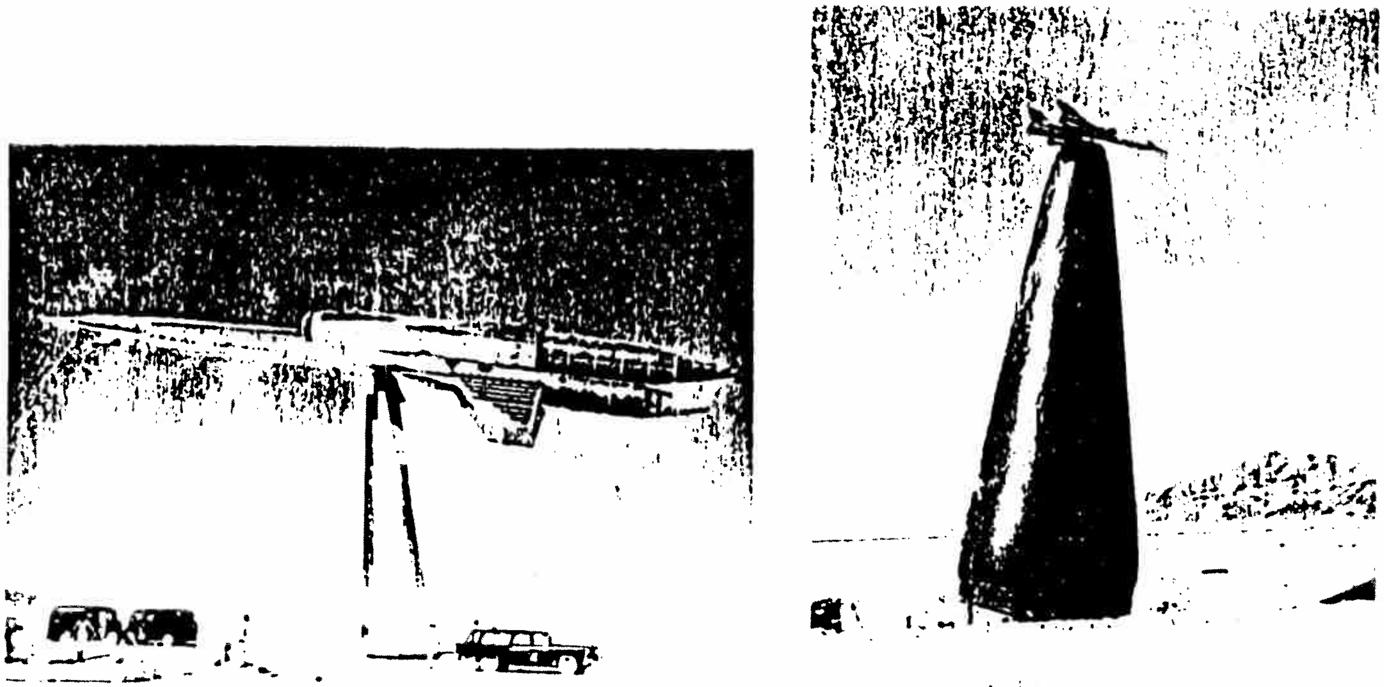

Figure 20. Full Scale Model on Post - 1/8 Scale Model on Neoprene Bag Support

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Figure 22. SR-71 in Flight Testing for Anti-Radar Evaluation