NACA

RESEARCH MEMORANDUM

EXPLORATORY MATERIALS AND MISSILE-NOSE-SHAPE TESTS IN A 4,000° F SUPERSONIC AIR JET

By Paul E. Purser and Russell N. Hopko

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

December 13, 1956
Declassified September 1, 1959

NACA RM L56J09

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EXPLORATORY MATERIALS AND MISSILE-NOSE-SHAPE TESTS IN A 4,000° F SUPERSONIC AIR JET

By Paul E. Purser and Russell N. Hopko

SUMMARY

Some exploratory materials and nose-shape tests have been made in a small supersonic air jet having a stagnation temperature of approximately 4,000° F at the Langley Aeronautical Laboratory. The materials considered included graphite, copper, carbon steel, and stainless steel; the nose shapes included 90° total-angle cones, hemispherical-face cylinders, and flat-face cylinders.

The tests indicated that graphite holds more promise as a heat-sink material than it had previously been considered to have. The tests also indicated that flat-face cylinders appear to be subject to approximately one-half the aerodynamic heat input as are hemispherical-face cylinders.

INTRODUCTION

Early analyses such as reference 1 indicated that one solution to the problem of survival of a long-range ballistic missile during atmospheric entry lay in using high-drag shapes and thick skins which would absorb the extreme aerodynamic heat input. Since the publication of reference 1, the National Advisory Committee for Aeronautics has expended considerable effort, both analytical and experimental, in an attempt to determine the best external shape for the high-drag nose and the best material for the thick heat-sink nose skin and in the development of research equipment with which to attack these two problems.

In the course of this general program, the Langley Laboratory has designed and built, on a laboratory scale, a ceramic pebble-bed heat exchanger which supplies air at stagnation temperatures up to slightly over 4,000° F to a small Mach number 2 nozzle. Some recent exploratory materials and nose-shape tests in this hot air jet have provided some qualitative data considered to be of sufficient interest to warrant immediate publication.

DESCRIPTION OF 4,000° F AIR JET

The laboratory-scale ceramic heat exchanger consists of a vertically mounted steel shell 2 feet in diameter and 11 feet high. The shell is lined with zirconium-oxide refractory blocks. A core of zirconium-oxide pebbles approximately 3/8 inch in diameter forms a bed 6 feet in depth and 8 inches in diameter. A water-cooled, 3/4-inch-diameter, supersonic nozzle is mounted at the top. A piston-actuated model-support system is mounted above the heat exchanger. This system effects a rapid entry of the model into the test jet. Figure 1 is a photograph of the ceramic heat exchanger and its allied equipment.

Fuel oil is burned with air and oxygen to give the desired flame temperature. The hot combustion products are forced down through the bed during the pebble-heating cycle. During the "blowdown" cycle, air flows through the pebble bed in a path the reverse of the heating cycle and exits through the nozzle. The stagnation temperature of the air equals the pebble temperature at the top of the bed, and during a blowdown the temperature of the bed drops approximately 10° to 15° F per second depending on the thoroughness with which the bed is heated.

The maximum bed temperature to which the heat exchanger may be utilized is limited by softening and "slumping" of the pebbles. The present equipment, therefore, can provide air stagnation temperatures up to slightly over 4,000° F which corresponds to sea-level flight at Mach numbers up to about 7. The air for the jet is supplied by the 100-pound-per-square-inch service system which limits the Mach number to 2 when a free jet is used at atmospheric exit pressure; the jet velocity, however, is approximately 5,200 feet per second when the stagnation temperature is 4,000° F. The Reynolds number based on stream conditions behind a normal shock is about 2 million per foot.

RESULTS AND DISCUSSION

Materials Tests

Background.- Many investigators have considered the use of graphite as a possible heat-sink material, but nearly all of them dismissed the use of graphite because of fears about its oxidation characteristics. A recent investigation conducted by Maxime A. Faget at the Langley Laboratory, however, indicates that the use of graphite holds considerable promise for the following reasons: There must be a balance between the heat inputs or sources (aerodynamic heating and oxidation) and the heat outputs or sinks (heat capacity, radiation, and, for graphite, the heat of sublimation). For many materials the rate of heat released by oxidation is of the same order of magnitude as the rate of heat absorbed by the sublimation or fusion; whereas, for graphite the amount of heat released by oxidation may be far smaller than the amount absorbed by sublimation so that the favorable effects of sublimation should outweigh the unfavorable oxidation effects. Also, because of its refractory nature, graphite may be allowed to reach higher temperatures which will decrease the aerodynamic heat input and increase both the radiative heat output and the usable heat capacity of the material.

Test results.- In order to obtain a better understanding of this problem, models 1 to 3 (see fig. 2) were tested in the air jet at a stagnation temperature of 4,000° F. The models were 90° total-angle cones made of AGR graphite, 347 stainless steel, and SAE 1018-1025 carbon steel. As shown in figure 3, the graphite model suffered far less damage in 17 seconds than did the steel models in about 10 seconds. It might be noted that the annular depression seen in the steel models in figure 3 is probably caused by the heating being more intense in the region where the nozzle-exit shock intersects the model surface than in other regions on the surface.

Further research.- Attempts are being made to improve graphite by impregnating it with compounds that either sublime or break down endothermically. In the first phase of this experiment, a flat-face graphite model was impregnated with ammonium chloride, which sublimes at about 1,000° F, and tested in the hot air jet at a stagnation temperature of 4,000° F. When the model was put into the jet, it began heating and the ammonium chloride started to sublime and leave the carbon. Because of the heat absorbed by the sublimation process and the action of the sublimed material as a transpired coolant, the impregnated model required 5.9 seconds to reach a visible glow, whereas an identical unprotected model glowed in 3.7 seconds. Continuation of this type of research with other materials will be desirable before the results can effectively be evaluated.

Nose-Shape Tests

Background.- For several years experience with heat-transfer measurements on hemispherical noses has indicated rather low Reynolds numbers for transition from laminar to turbulent flow and, thus, from low to high heat-transfer rates on the hemispherical surface. Maximum noted local values of the transition Reynolds number have been of the order of 1 million, and the region from 30° to 50° around the nose from the stagnation point appears most susceptible to transition (see, for example, ref. 2). In some unpublished studies by P. R. Hill of the Langley Laboratory, causes of early transition were sought which might be fundamentally associated with geometry. Among the factors considered were the local Reynolds numbers on the body, rotational flow behind the bow shock and disturbances in the local flow where it reached transonic speeds in expanding around the nose, since the trouble seemed to begin at about the transonic region. The idea of the flat face to reduce the local Reynolds numbers, to flatten the bow shock to reduce vorticity, and to reduce the physical extent of the transonic region was arrived at by Hill in 1955. It seemed that the naturally lower Reynolds number per foot of the flow on the flat face would permit a longer physical run of laminar flow; in addition, the more rapid growth of area with distance from the stagnation point on the flat face as compared with that on the hemisphere would tend to thin and stabilize the laminar layer. The flat face would serve to reduce the extent of the transonic flow region also, since the flow would traverse the complete face before reaching the sonic line. Regardless of any stabilizing effects on the boundary layer, the flat face would have a lower value of the velocity gradient along the surface near the stagnation region than would the hemisphere because of its larger radius of curvature, and this decrease in velocity gradient would result in lower heat transfer on the flat face for either laminar or turbulent boundary layers (see ref. 3). A preliminary test in a jet produced by an acid-ammonia rocket motor with a flat-face model verified the superiority of this shape. The remaining question was simply that of determining the optimum corner shape, and research programs were initiated for this purpose.

Test results.- In order to obtain a direct qualitative comparison of the heat transfer to hemispherical-face and flat-face cylinders, models 4 to 8 were tested in the 4,000° F air jet. The temperatures noted in figure 3(a) are the stagnation temperatures at the time of model entrance into the jet. A decrease occurs in stagnation temperature with "blowdown" time of 10° to 15° F per second as mentioned previously in the description of the ceramic heat exchanger. Models 4 to 6 were made of stainless steel and consisted of a hemisphere, a flat face with rounded corners, and a flat face with sharp corners. The hemisphere model started to burn and to melt in about 12 seconds; the flat-face models were relatively undamaged after about $2\frac{1}{2}$ times that period of time in the jet. Similar hemisphere and rounded-corner flat-face models were made of copper (models 7 and 8). For these models the hemisphere started to melt in 11.3 seconds and the flat face started in 20.8 seconds. Again the flat-face model suffered less damage than the hemisphere after a longer time in the jet. Figures 3(a), (c), and (d) show the appearance of models 4 to 8 after the test; the relative heat transfer as indicated by the relative damage to the models is quite evident. Even after more than 30 seconds in the jet the corners on model 6 appear to have suffered no damage. The comparative times to melt for the copper models indicate that the general level of the aerodynamic heating on the flat face is about one-half that on the hemisphere; this difference in aerodynamic heating is in qualitative agreement with the trends noted in some recent theoretical work by Van Driest (ref. 3).

General observations.- The lack of damage to the sharp corners of model 6 may not continue at angles of attack other than zero. In the preliminary tests of a flat-face cylinder in a 3,900° F jet produced by an acid-ammonia rocket motor, some damage occurred to the sharp corners when the support strut loosened and the model assumed an angle of attack of about 5°. This is one of the particular points of concern which requires more research. Unpublished data at the Ames Aeronautical Laboratory (following the investigation reported in ref. 4) indicate that the flat-face models may have less dynamic stability than hemispherical-face models and, thus, may be more susceptible to increased heating due to angle of attack.

CONCLUDING REMARKS

From some exploratory tests in a 4,000° F supersonic air jet it appears that graphite offers considerable promise as a heat-sink material; the effectiveness of the graphite can apparently be increased by impregnation with other materials. Similar tests indicate that the aerodynamic heat transfer to flat-face cylinders is appreciably less than to hemispherical-face cylinders. These results are qualitative in nature and continuation of research to provide more quantitative data on both the materials and nose-shape problems is desirable.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 17, 1956.

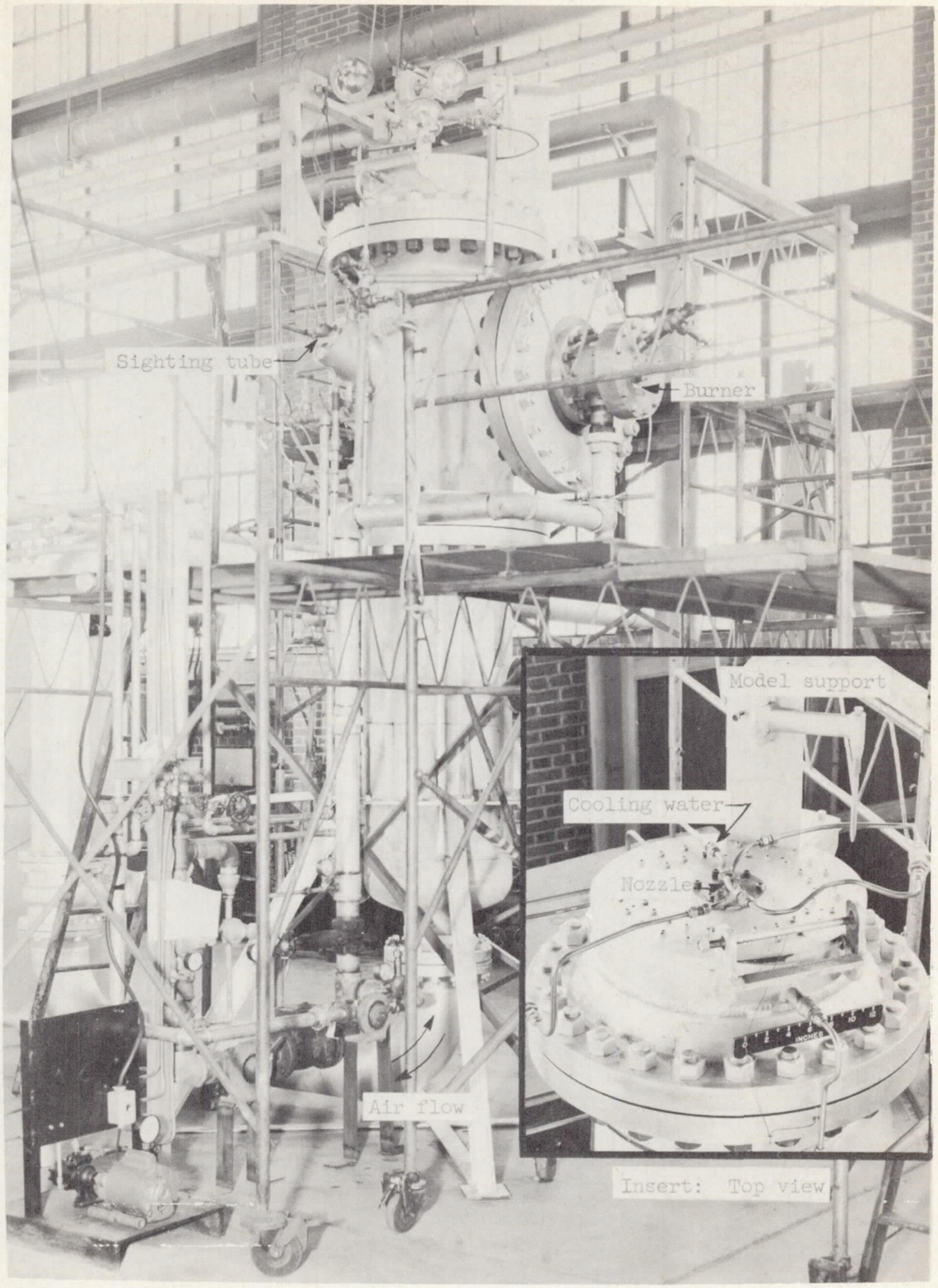
REFERENCES

1. Allen, H. Julian, and Eggers, A. J., Jr.: A Study of the Motion and Aerodynamic Heating of Missiles Entering the Earth's Atmosphere at High Supersonic Speeds. NACA RM A53D28, 1953.

2. Chauvin, Leo T., and Maloney, Joseph P.: Experimental Convective Heat Transfer to a 4-Inch and 6-Inch Hemisphere at Mach Numbers From 1.62 to 3.04. NACA RM L53L08a, 1954.

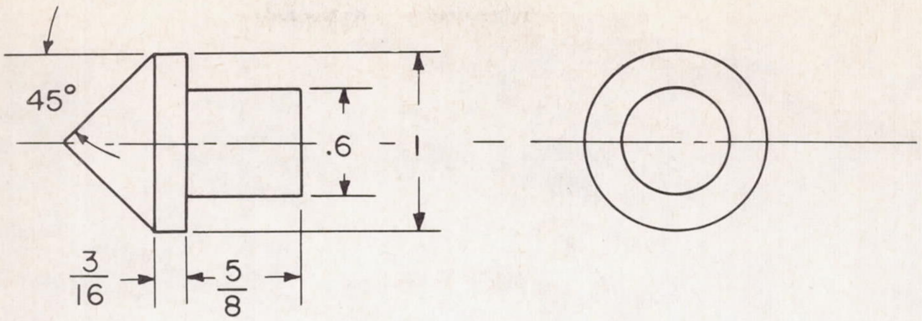
3. Van Driest, E. R.: The Problem of Aerodynamic Heating. Rep. No. AL-2303, North American Aviation, Inc., May 1, 1956.

4. Allen, H. Julian: Motion of a Ballistic Missile Angularly Misaligned With the Flight Path Upon Entering the Atmosphere and Its Effect Upon Aerodynamic Heating, Aerodynamic Loads, and Miss Distance. NACA RM A56F15, 1956.

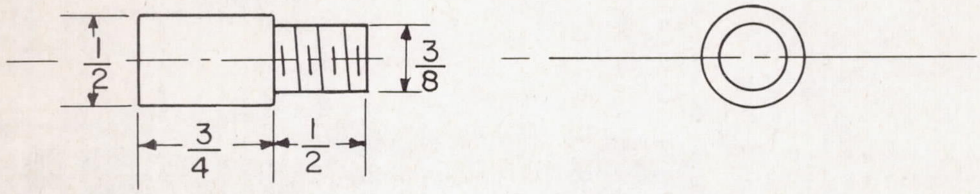


L-93426.1

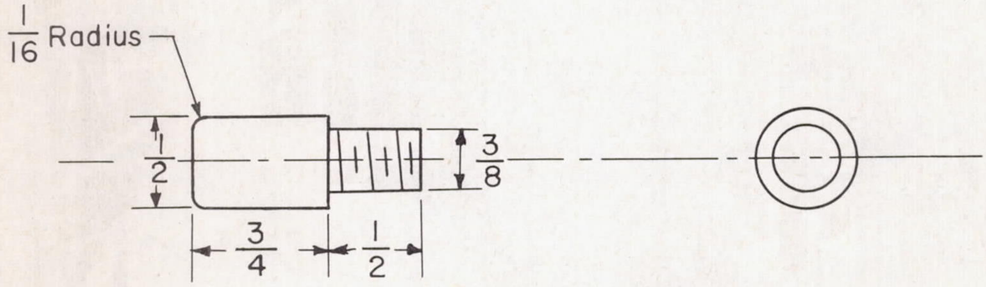
Figure 1.- General arrangement of laboratory-scale ceramic heat exchanger.



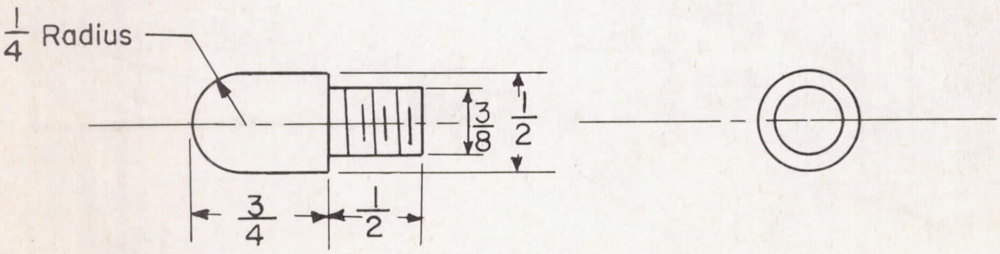
Models 1, 2 & 3



Model 6

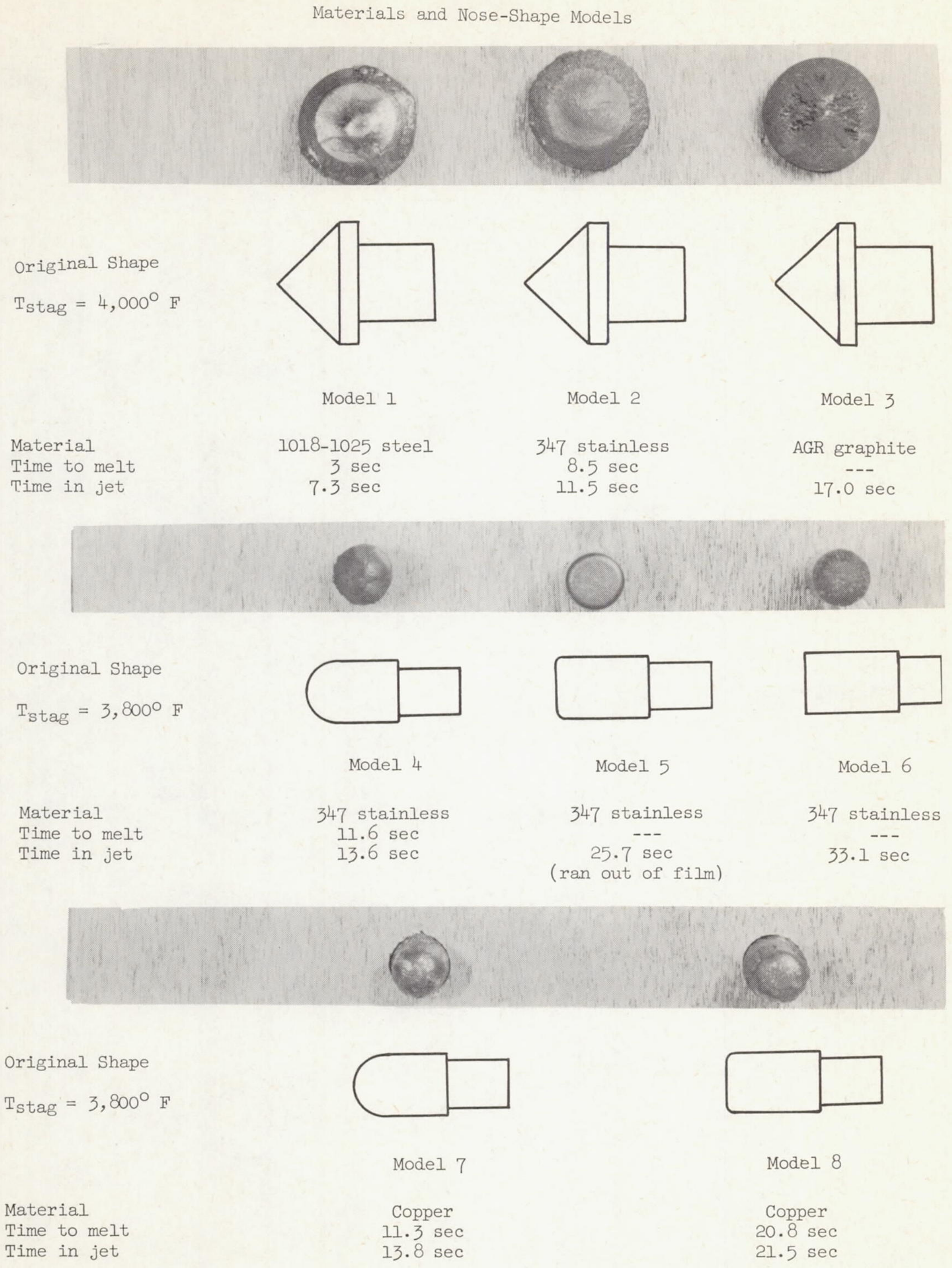


Models 5 & 8



Models 4 & 7

Figure 2.- Sketch of models. (All dimensions are in inches.)

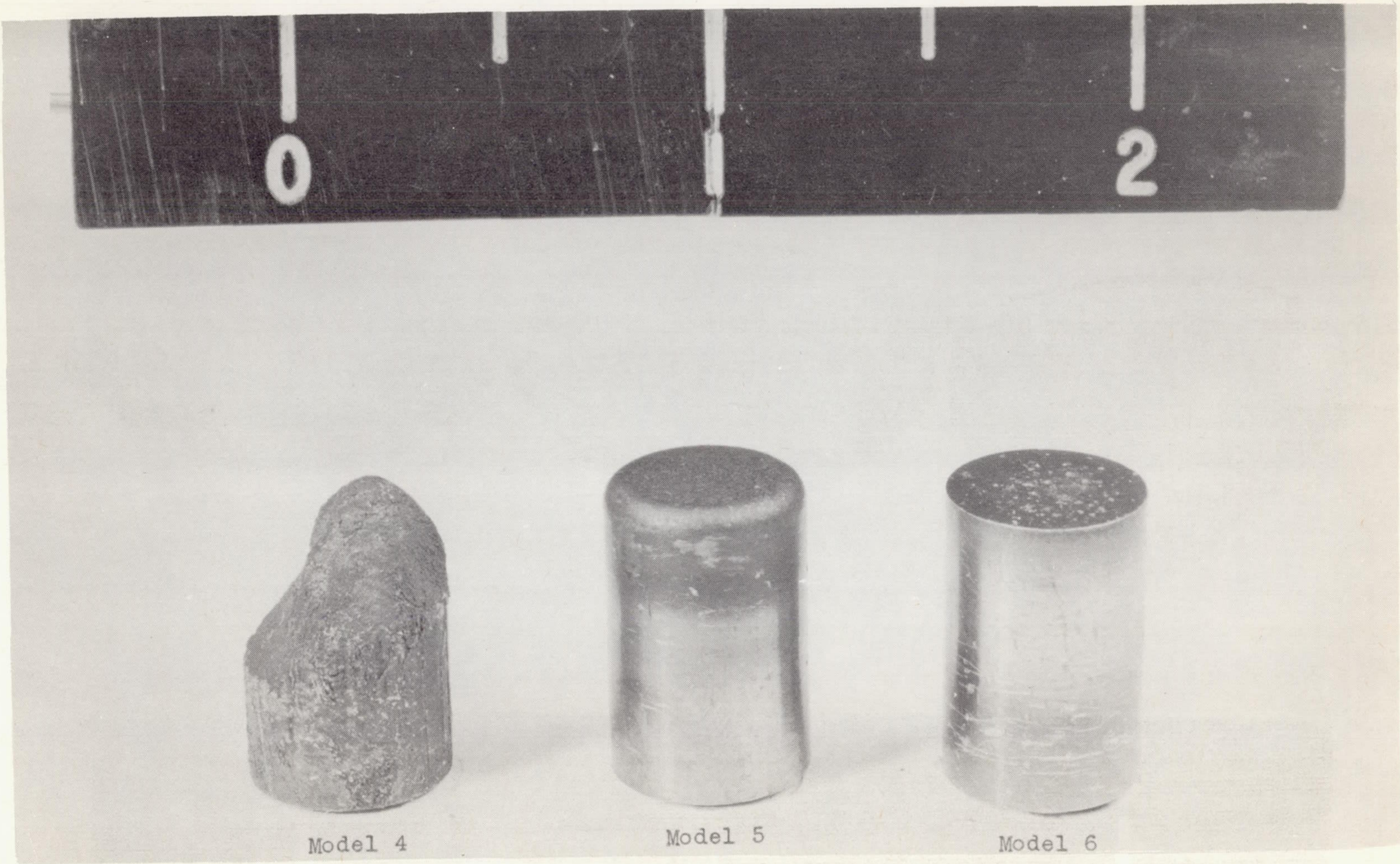


(a) Models 1 to 8.

Figure 3.- Models tested.

(b) Models 1, 2, and 3. L-95278.1

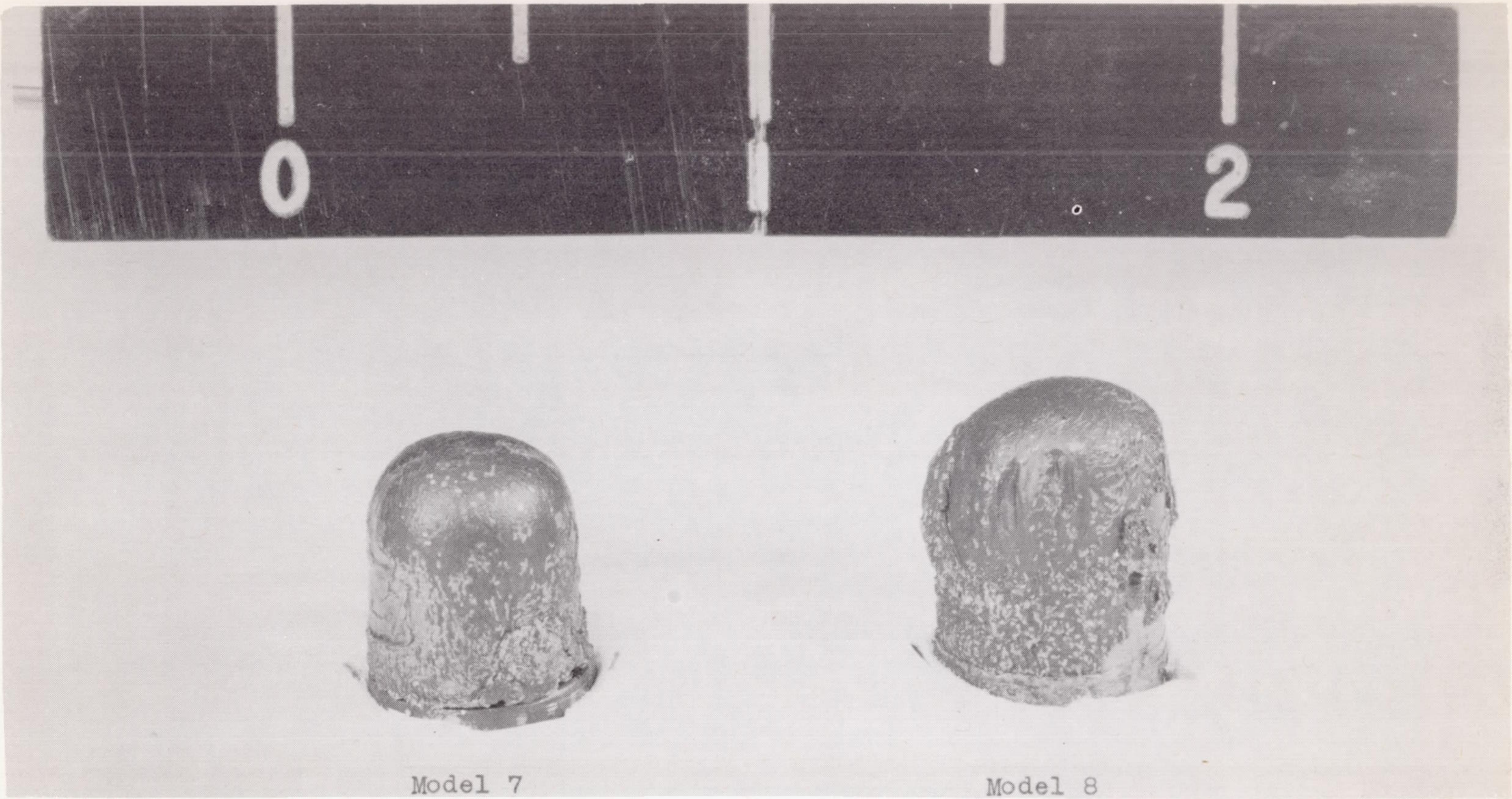
Figure 3.- Continued.



L-95280.1

(c) Models 4, 5, and 6.

Figure 3.- Continued.



(d) Models 7 and 8.

L-95281.1

Figure 3.- Concluded.