HD0L4

[redacted] [redacted]

Copy
RM L5

14911

20 JAN 1

0144719

TECH LIBRARY KAFB, NM

NACA RM L57K15

7818

NACA

RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF GRAPHITE, SILICON CARBIDE, AND SEVERAL POLYMER—GLASS-CLOTH LAMINATES IN A MACH NUMBER 2 AIR JET AT STAGNATION TEMPERATURES OF 3,000° F AND 4,000° F

By Francis W. Casey, Jr., and Russell N. Hopko

Langley Aeronautical Laboratory
Langley Field, Va.

CLASSIFIED DOCUMENT

This material contains information affecting the National Defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
January 9, 1958

[redacted]

[redacted]

Classification cancelled (or changed to Unclassified)

By authority of NASA Tech Pub Announcement [illegible]
(OFFICER AUTHORIZED TO CHANGE)

By 3 Marks

NK

GRADE OF OFFICER MAKING CHANGE)

23 Feb. 61
DATE

TECH LIBRARY KAFB, NM
0144719

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF GRAPHITE, SILICON CARBIDE, AND SEVERAL POLYMER—GLASS-CLOTH LAMINATES IN A MACH NUMBER 2 AIR JET AT STAGNATION TEMPERATURES OF 3,000° F AND 4,000° F

By Francis W. Casey, Jr., and Russell N. Hopko

SUMMARY

Several materials including graphite, silicon carbide, and a number of polymer—glass-cloth laminated constructions have been tested at temperatures of 3,000° F and 4,000° F in a laboratory-scale ceramic-heated air jet. These tests were directed at utilizing four possible mechanisms for the alleviation of the aerodynamic-heating problem of hypersonic aircraft. These mechanisms include radiative heat transfer, pyrolysis, fusion, and mass-transfer cooling by ablation.

The tests indicate that polymeric materials have definite advantages in high-temperature environments and show promise as materials for high-speed aircraft.

INTRODUCTION

The flight conditions encountered by hypersonic aircraft have caused a great emphasis to be placed on materials. In order to study some of the capabilities and limitations of materials, the Langley Laboratory has in operation a Mach number 2 air jet having obtainable temperatures of 4,000° F (ref. 1).

One of the research programs at the Langley Laboratory is the observation of materials while they are subjected to high-temperature, high-velocity air flow. Various materials and nose shapes have been tested and some of the resulting data are reported in reference 1.

The present paper is concerned with characteristics of several materials at high temperatures. Although some of the materials tested, such as the polymer—glass-cloth laminates, are not usually considered to have high-temperature properties, they were included because they were believed to show promise in certain specific applications.

The materials tested include graphite, silicon carbide, and a number of high-temperature polymer—glass-cloth laminates. The materials were supplied by the Missile and Ordnance Systems Department of General Electric Co., Philadelphia, Pa.

SYMBOLS

V	velocity, ft/sec
T	temperature, °R
T_s	stagnation temperature, °F or °R
P	pressure, lb/sq in. abs
M	Mach number

GENERAL CONSIDERATIONS

Previous investigations have indicated that the problem of aerodynamic heating may be alleviated significantly by employing materials which utilize the mechanisms of radiation, pyrolysis, fusion, and mass transfer by ablation.

For effective use of radiation as a heat-dispersing mechanism, the operating temperature of the material must be high. The materials which can be exposed to these high operating temperatures are relatively limited. Materials such as graphite and silicon carbide have the thermophysical properties suitable for exposure to elevated temperature for extended periods of time. These materials, however, have high thermal conductivities and the temperature will be high throughout any structure which utilizes them.

Polymers, organic substances of high molecular weight, on the other hand, have low thermal conductivities. The surfaces of these materials may rise to a sufficiently high temperature to utilize radiative heat transfer for heat dispersion while the interior of the material remains at a substantially lower temperature.

Polymeric materials exhibit other properties which have interesting possibilities for heat absorption. For example, the transition of the polymer from the solid state to the liquid state requires an input of heat energy equivalent to the heat of fusion. An additional high-absorption possibility may be recognized from the pyrolysis phenomenon exhibited by some polymers. Pyrolysis is the chemical decomposition, sustained by heat, of a large molecule into two or more simpler molecules. In order to form the simpler molecules, certain chemical bonds must be broken in the large molecule and reestablished in the smaller molecules. If the bond energy of the simpler molecules is equal to or greater than the bond energy of the parent molecule, then energy must be added to the system to make the reaction take place. The reaction is endothermic and its heat-absorbing capabilities will depend on the heat of reaction.

Another possible cooling phenomenon exhibited by polymers falls into a mass-transfer classification. When polymers reach a molten state in a high-velocity flow system, the molten material tends to move in the direction of flow. In some cases, this liquid polymeric material is adherent to the solid material over which it passes. This phenomenon may prevent the solid surface from rising to a higher temperature.

MODELS, TESTS, AND MATERIALS

The models tested were cylindrical rods 3 inches long with a hemispherical nose 1/2 inch in diameter. The laminations of the fiber and fabric models were parallel to the flow of the jet. A drawing of the model is shown in figure 1. The tests were made at stagnation temperatures of 3,000° F and 4,000° F in the ceramic-heated air jet described in reference 1. The jet properties are shown in figure 2. Details on the position of the models in the jet can be found in reference 1. The data for this investigation were taken with a motion-picture camera at approximately 130 frames per second. No effort should be made to compute mass loss from the photographs since the position of the model varies slightly from frame to frame. The timing shown in the photographs indicates seconds and tenths of seconds.

The sources and compositions of the materials investigated are given as follows:

Model 1: Graphite, grade 580, supplied by Speer Carbon Co., St. Marys, Pa. This is known as a fine-grain mold stock grade and has a specific gravity of 1.60 to 1.70.

Model 2: "KT" silicon carbide, supplied by the Carborundum Co. This is a self-bonded silicon carbide.

Model 3: Phenolic resin loaded with magnesia powder, a special mix made by Norton Company, Worcester, Mass. The test specimens were machined from blocks.

Model 4: High-temperature phenolic resin no. 37-9-X with macerated Refrasil cloth, supplied by Cincinnati Testing Laboratory. A specific gravity of approximately 1.63 was found. Refrasil is a silica fiber supplied by H. I. Thompson Fiberglass Co., Los Angeles, Calif. It is said to be made by chemical extraction of glass fibers, so that the resulting material is about 98 percent silica.

Model 5: High-temperature phenolic resin no. 37-9-X with fine-weave glass cloth, supplied by Cincinnati Testing Laboratory.

Model 6: Silicone resin with glass-cloth reinforcement, style GSC, supplied by Taylor Fibre Company, Norristown, Pa. This has a nominal specific gravity of 1.88 and 35 percent silicone resin DC 2103 by weight. The samples were machined from laminated sheet.

Model 7: Melamine-glass cloth, Textolite no. 11508, supplied by General Electric Company. The samples were machined by an outside fabricator, apparently from laminated rod stock. The Langley Laboratory found a specific gravity of approximately 1.85.

Model 8: Vulcanized fiber, commercial grade, supplied by Taylor Fibre Company. This is made by treating paper (cellulose) with zinc chloride and leaching.

Model 9: Phenolic nylon, 53 percent by weight of phenolic resin with staple nylon cloth, supplied by Taylor Fibre Company (style NS). Nominal specific gravity is 1.15.

TEST RESULTS

Graphite

Figure 3 shows graphite in a 4,000° F air jet at discrete time intervals. For the duration of the test, graphite appeared to suffer little damage. The photographs show a slight change in the model; this is the result of combined effects of oxidation and erosion.

Silicon Carbide

Figure 4(a) shows a history of silicon carbide at a jet stagnation temperature of 3,000° F. This material appeared to withstand the elevated-temperature environment remarkably well. An examination of the material after testing revealed that the surface had encountered some erosion and oxidation effects, but these were minor. Figure 4(b) shows silicon carbide at a jet stagnation temperature of 4,000° F. At this temperature, some melting occurred at the extreme forward section of the model. This molten material was believed to consist of silicon dioxide formed during the oxidation of the silicon carbide. After 10 seconds of exposure the effects of erosion and oxidation were more pronounced at this higher temperature; however, there was no extreme surface deformation for the duration of the 20-second exposure.

Phenolic Resin and Magnesia

Figure 5 gives photographic coverage of phenolic resin and magnesia at a jet stagnation temperature of 4,000° F. This material showed some mass loss through ablation at the forward section; the main source of mass loss was erosion. The erosion is believed to have been initiated by the appearance of small fissures possibly caused by thermal stresses in the material.

Phenolic Resin and Refrasil Cloth

Figures 6(a) and 6(b) illustrate the behavior of this material at jet stagnation temperatures of 3,000° F and 4,000° F, respectively. The model exhibited somewhat uniform ablation at a jet stagnation temperature of 3,000° F but the test at a jet stagnation temperature of 4,000° F shows some irregularity in flow. The model appeared to delaminate in 10 seconds at a jet stagnation temperature of 4,000° F.

Phenolic Resin and Fine-Weave Glass Cloth

Figure 7(a) gives the time history of this test at a jet stagnation temperature of 3,000° F. The heating of this material was very local. The ablation was fairly uniform and the ablated material adhered to the model surface. The nose remained hemispherical throughout the test.

Photographic records of the test at a jet stagnation temperature of 4,000° F are shown in figure 7(b). The performance of the material was similar to that at a jet stagnation temperature of 3,000° F. The lamination held for the entire test.

Silicone Resin and Glass Cloth

Figure 8(a) shows the behavior of this model at a jet stagnation temperature of 3,000° F. The surface melting of this material began almost immediately after entrance into the jet. The material delaminated at 9 seconds and the model was destroyed rapidly. The lamination in this material was parallel to the flow and this condition cannot be considered as best for testing.

Figure 8(b) gives a photographic history of this test at a jet stagnation temperature of 4,000° F. Again, surface melting was rapid. The model became roughly conical during the test and the molten material appeared to leave the surface immediately after reaching a liquid state. This model also delaminated.

Melamine and Glass Cloth

Figure 9(a) illustrates the behavior of this material at a jet stagnation temperature of 3,000° F. The melamine resin softened and extruded from the weave of the glass cloth upon the initial exposure to the jet. The ablated material flowed smoothly and evenly from the nose surface toward the rear of the model. The nose remained hemispherical during the ablation and the lamination remained intact. Figure 9(b) shows the behavior of the material at a jet stagnation temperature of 4,000° F.

Nylon Fabric and Phenolic Resin

Figure 10 shows that this material began to burn and char almost instantly. Large sections of the model broke away.

Vulcanized Fabric

Figure 11 shows this material in test. The material exhibited mass loss mainly by vaporization at a jet stagnation temperature of 4,000° F as at a jet stagnation temperature of 3,000° F. The material showed some surface melting at 8 seconds but failed from thermal stresses before ablation became rapid.

CONCLUDING REMARKS

Observations of several materials subjected to a high-temperature jet indicate that certain materials have potential for absorbing heat other than their sensible heat capacity. Some of the materials observed may decrease heating effects by the mechanisms of radiation, pyrolysis, fusion, and mass transfer.

Materials such as graphite and silicon carbide may utilize the mechanism of radiation efficiently because of their high operating temperatures. These materials, however, have high thermal conductivities and temperatures will be high throughout any structure which utilizes them.

The polymer-based materials such as laminates of phenolic or melamine resin and glass cloth show promise as short-duration high-temperature materials. The total survival times of these polymer—glass-cloth constructions do not compare with those of graphite or silicon carbide; however, they may have uses in certain specific applications. These materials have low thermal conductivities and tend to restrict the elevated temperatures of a structure to the surface. This allows the materials to make use of radiation without subjecting the internal structure to high temperatures. The polymers may also utilize the heat-absorption mechanisms of pyrolysis and mass transfer.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 22, 1957.

REFERENCE

1. Purser, Paul E., and Hopko, Russell N.: Exploratory Materials and Missile-Nose-Shape Tests in a 4,000° F Supersonic Air Jet. NACA RM L56J09, 1956.

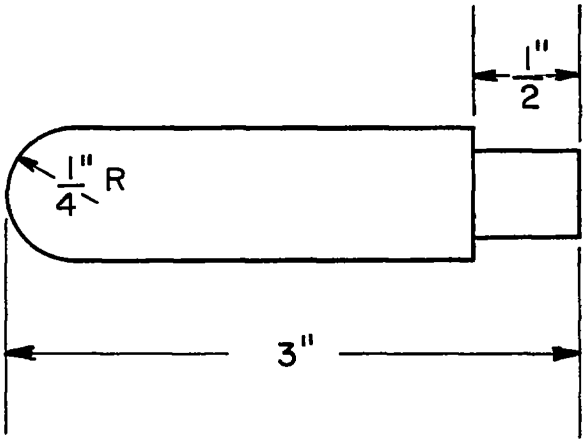


Figure 1.- Sketch of model.

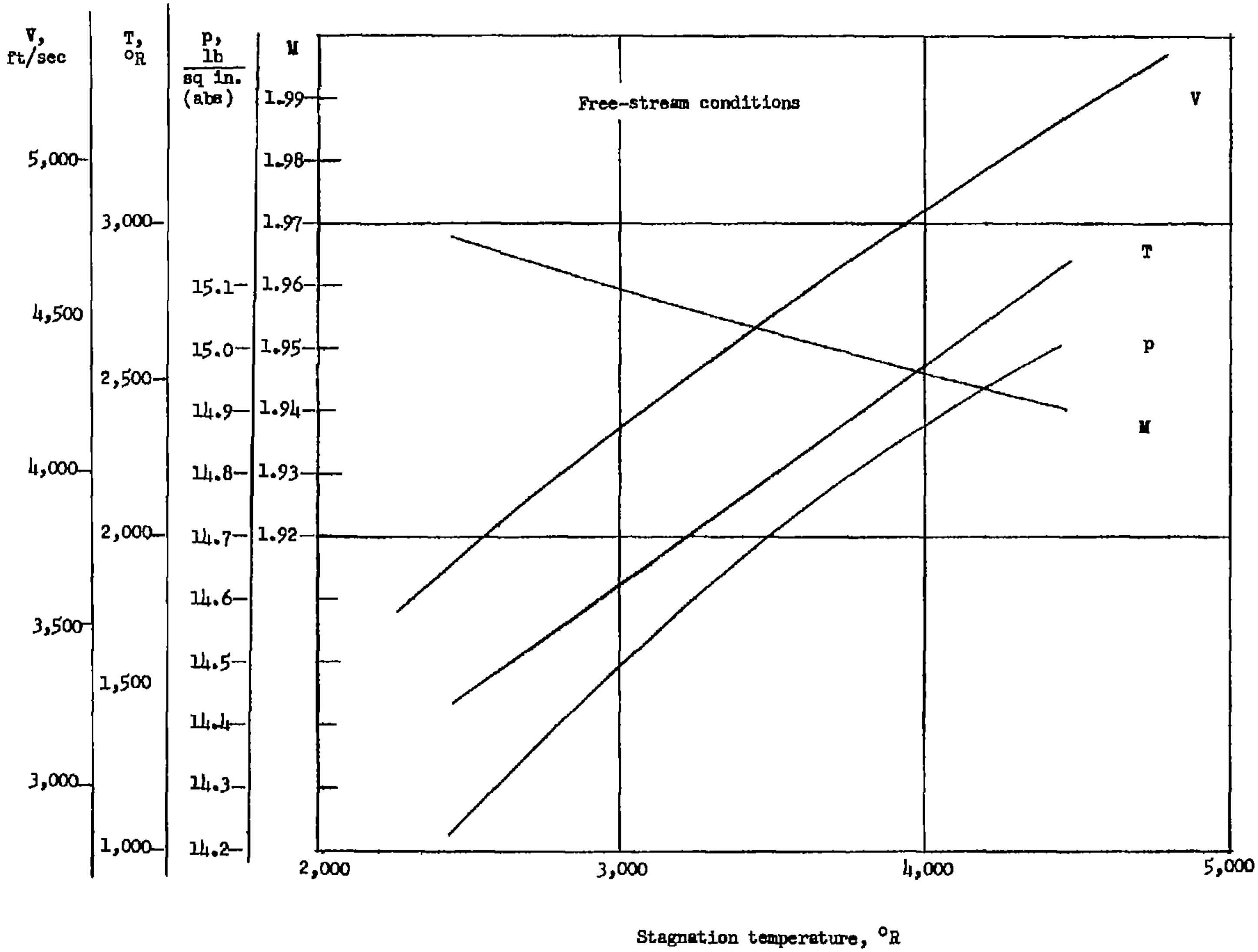
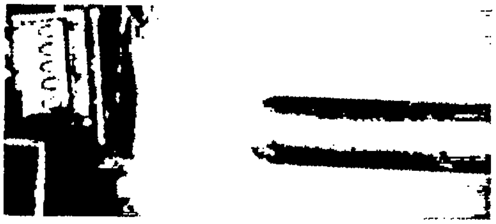
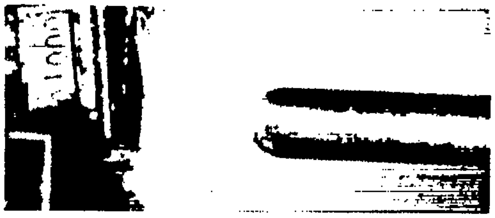


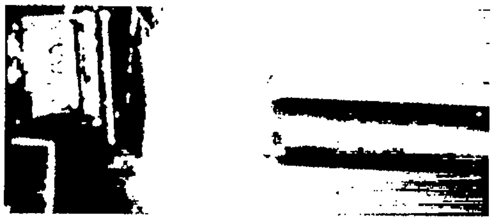
Figure 2.- Theoretical jet conditions.



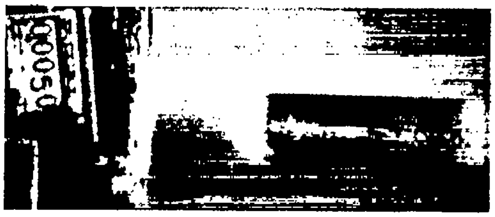
0 sec



1 sec



2 sec

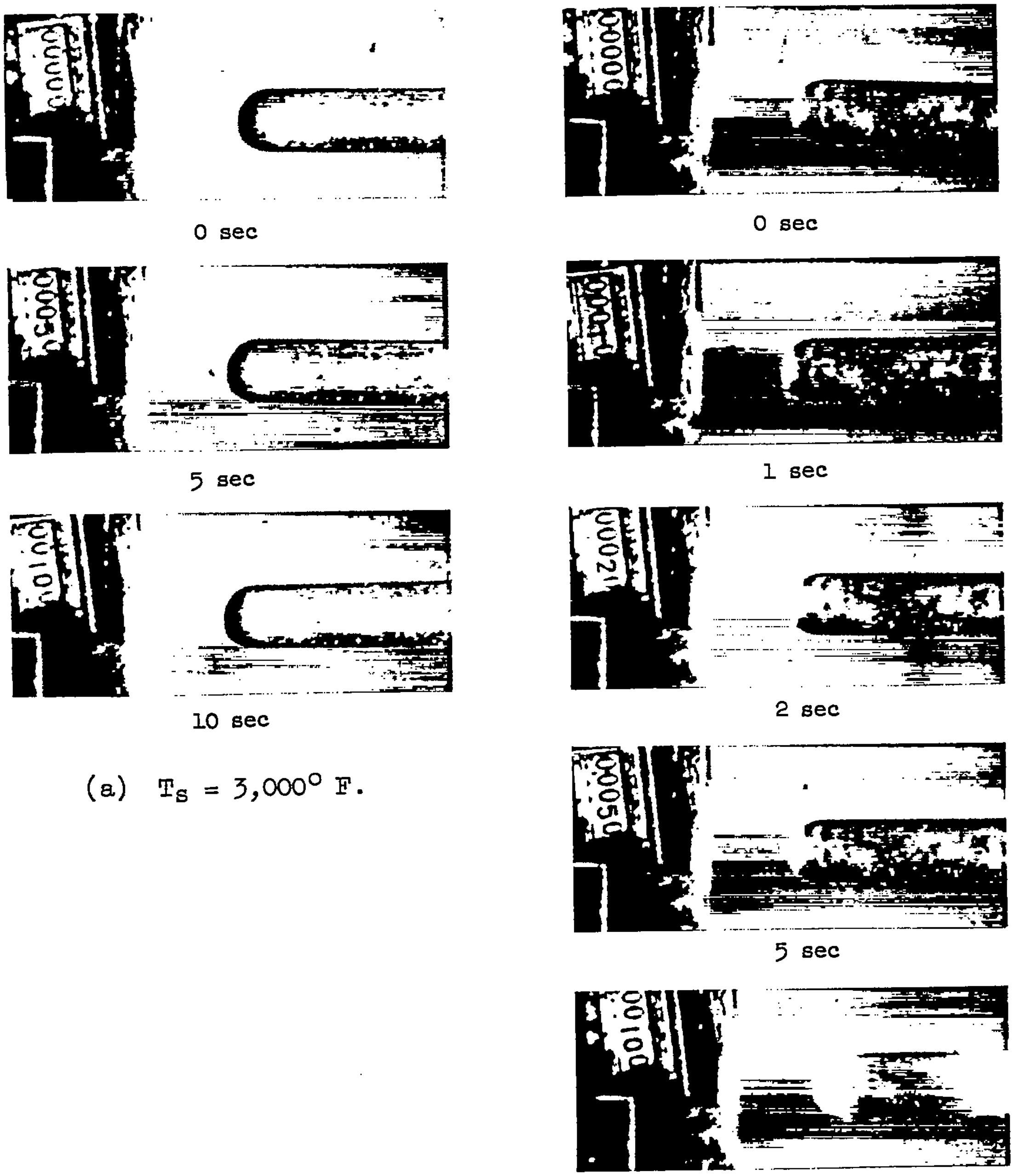


5 sec

10 sec

L-57-4407

Figure 3.- Photographs of graphite (model 1) in the ceramic-heated air jet. $T_s = 4{,}000^\circ$ F.

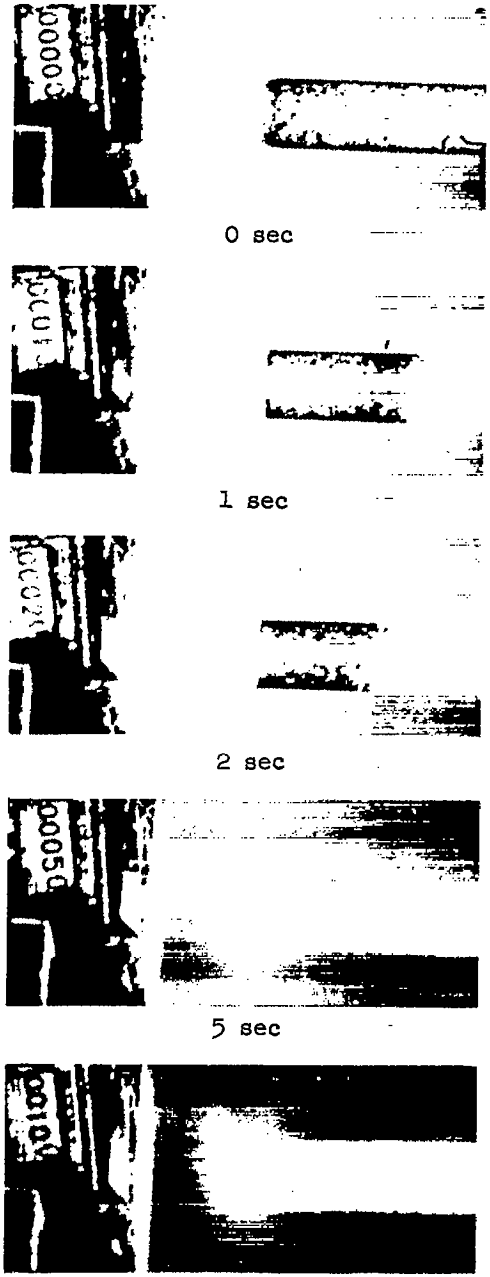


(a) T_s = 3,000° F.

(b) T_s = 4,000° F.

L-57-4408

Figure 4.- Photographs of silicon carbide (model 2) in the ceramic-heated air jet.



0 sec

1 sec

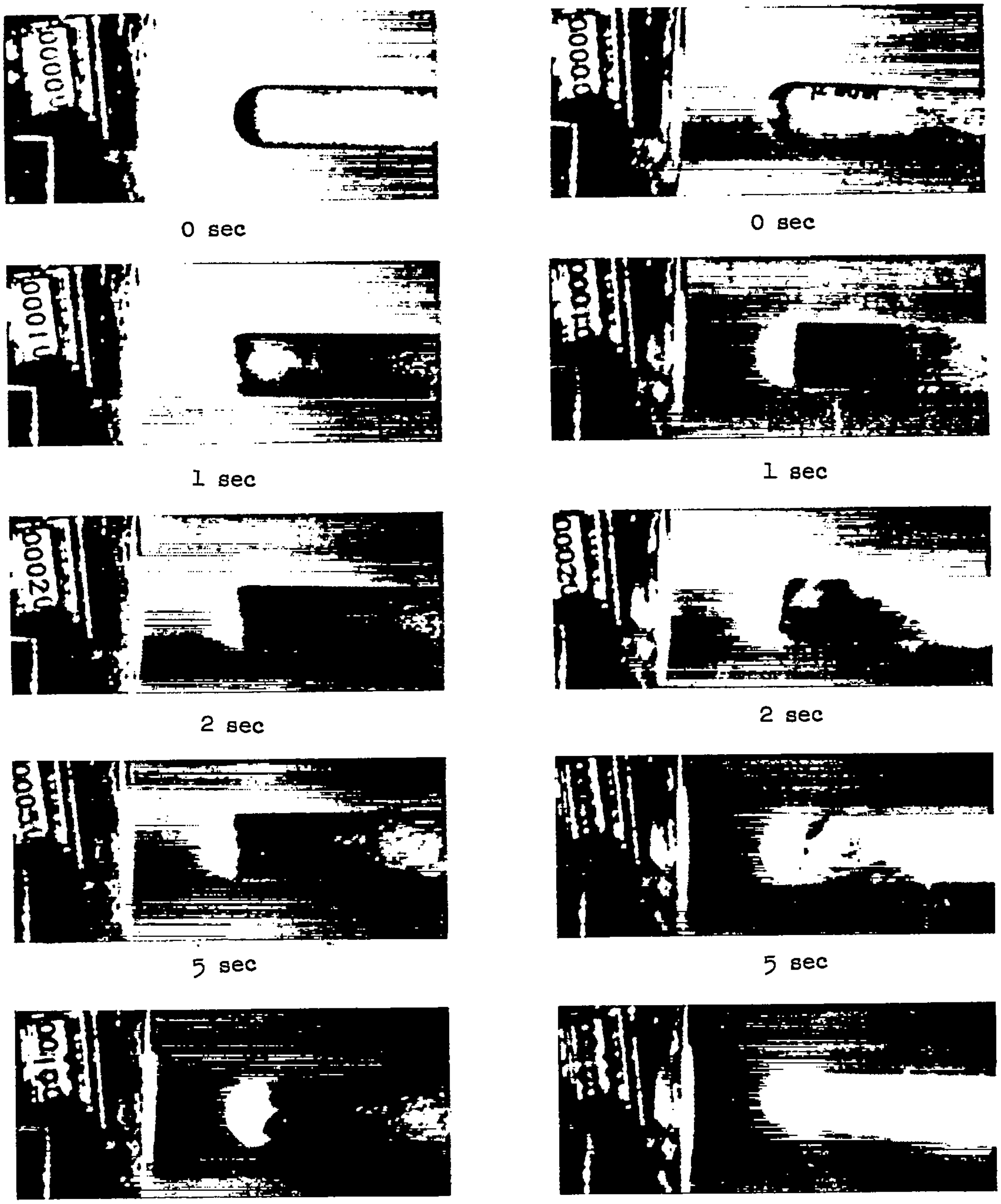
2 sec

5 sec

10 sec

L-57-4409

Figure 5.- Photographs of phenolic resin and magnesia (model 3) in the ceramic-heated air jet. $T_s = 4{,}000^\circ$ F.



0 sec

0 sec

1 sec

1 sec

2 sec

2 sec

5 sec

5 sec

10 sec

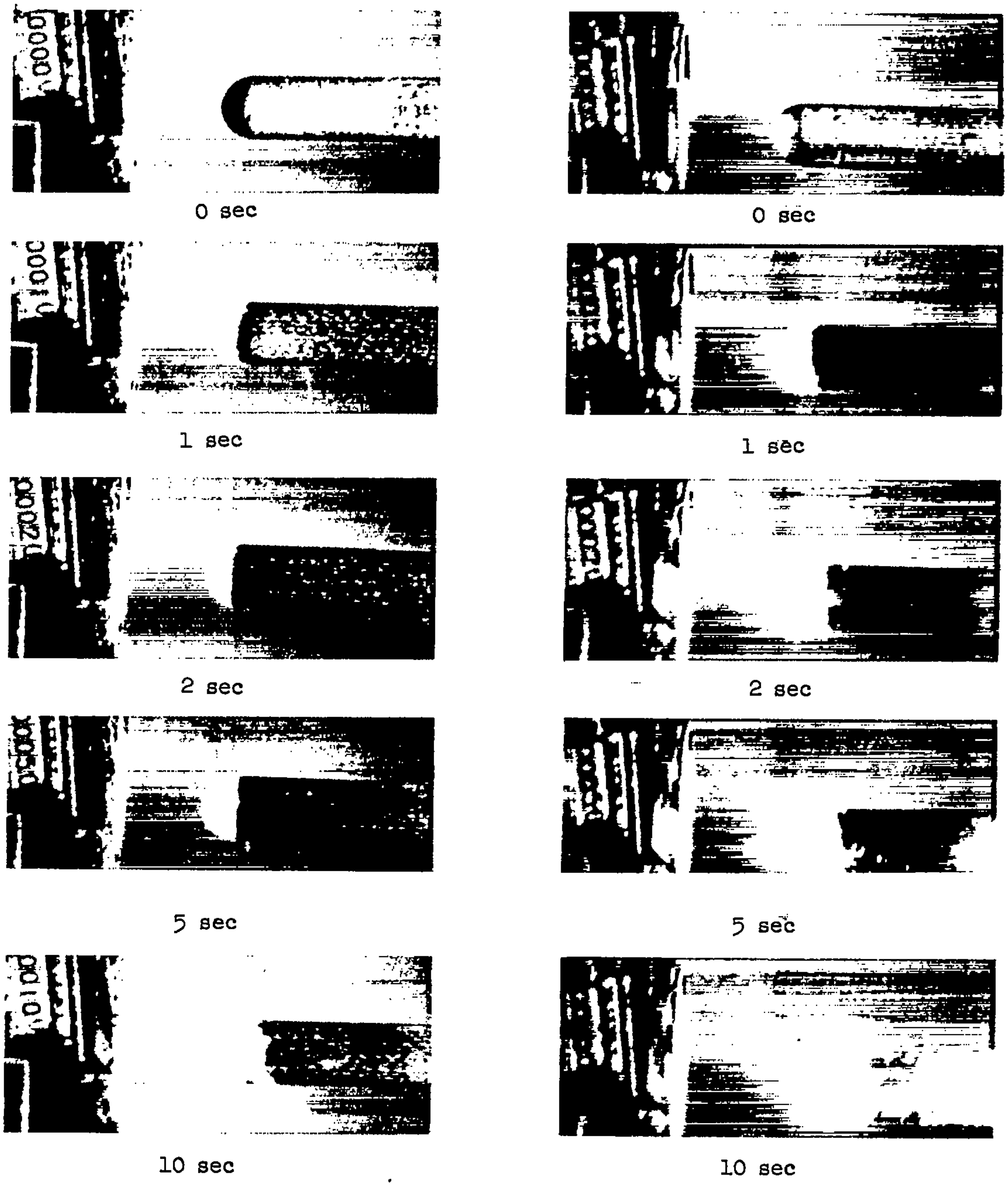
10 sec

(a) $T_s = 3,000^\circ$ F.

(b) $T_s = 4,000^\circ$ F.

L-57-4410

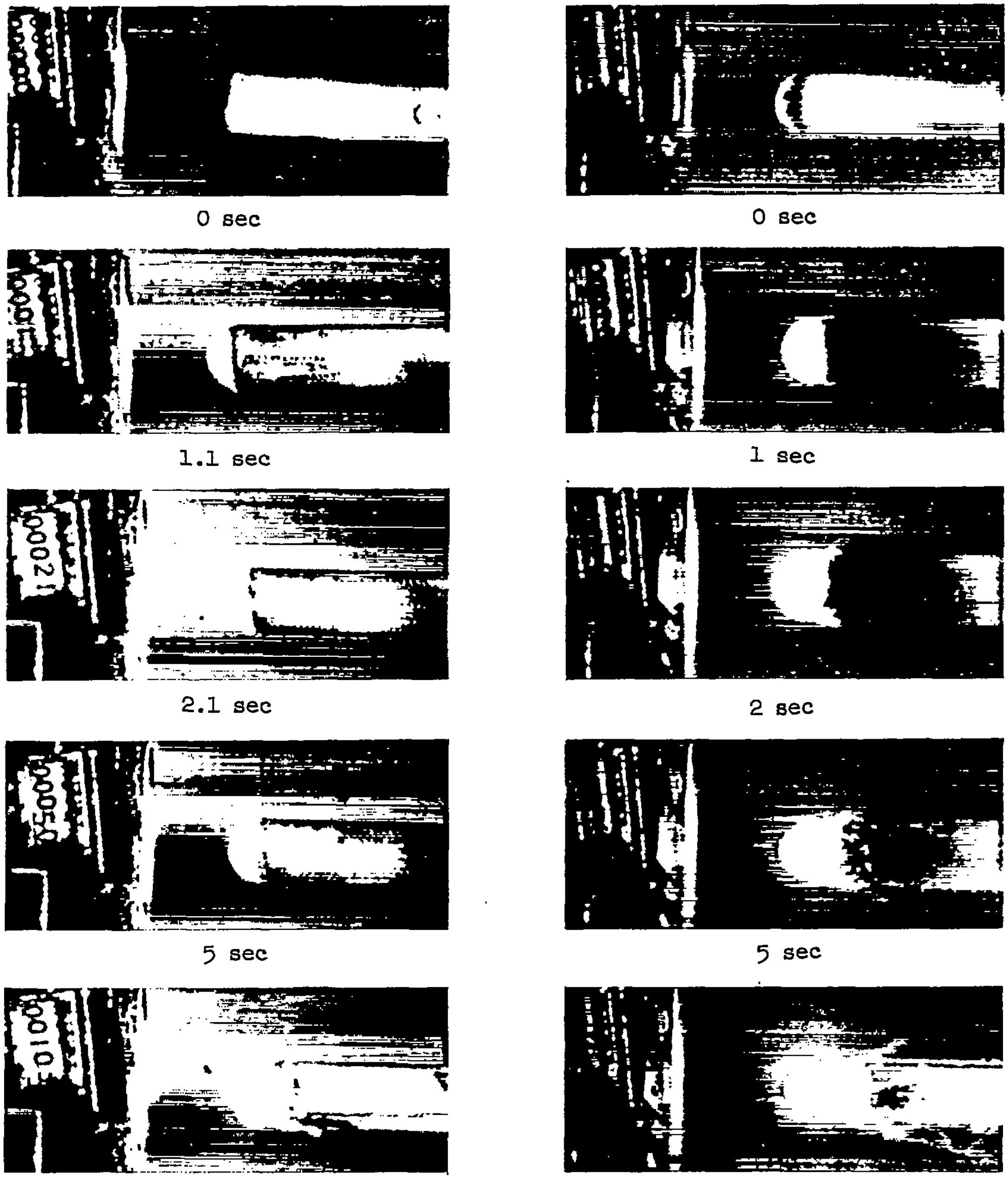
Figure 6.- Photographs of phenolic resin and Refrasil cloth (model 4) in the ceramic-heated air jet.



(a) $T_s = 3,000^\circ$ F. (b) $T_s = 4,000^\circ$ F.

L-57-4411

Figure 7.- Photographs of phenolic resin and fine-weave glass cloth (model 5) in the ceramic-heated air jet.



0 sec | 0 sec

1.1 sec | 1 sec

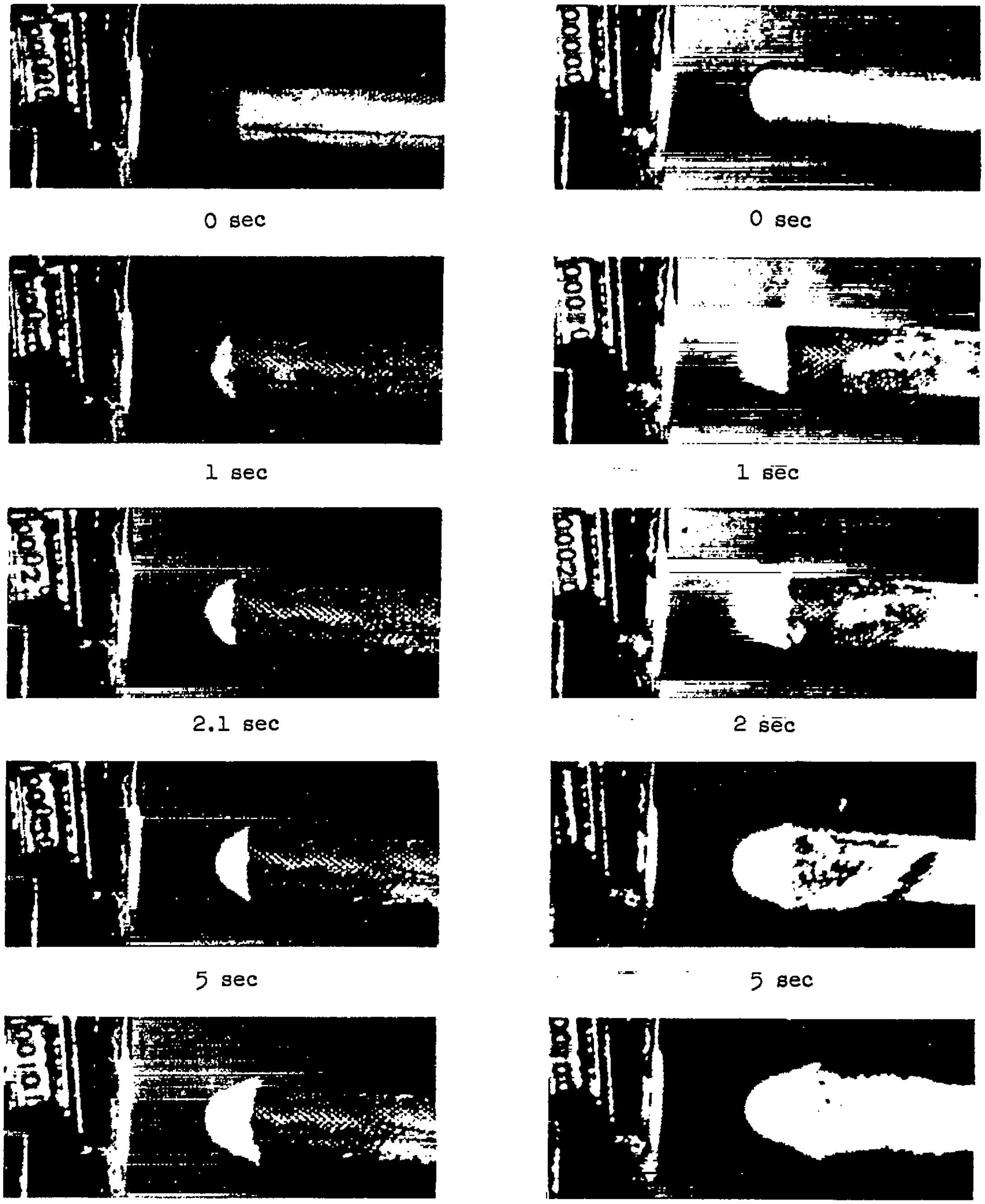
2.1 sec | 2 sec

5 sec | 5 sec

10.3 sec | 10 sec

(a) $T_s = 3{,}000^\circ$ F. (b) $T_s = 4{,}000^\circ$ F. L-57-4412

Figure 8.- Photographs of silicone resin and glass cloth (model 6) in the ceramic-heated air jet.



L-57-4413

(a) T_s = 3,000° F.   (b) T_s = 4,000° F.

Figure 9.- Photographs of melamine resin and glass cloth (model 7) in the ceramic-heated air jet.

0 sec

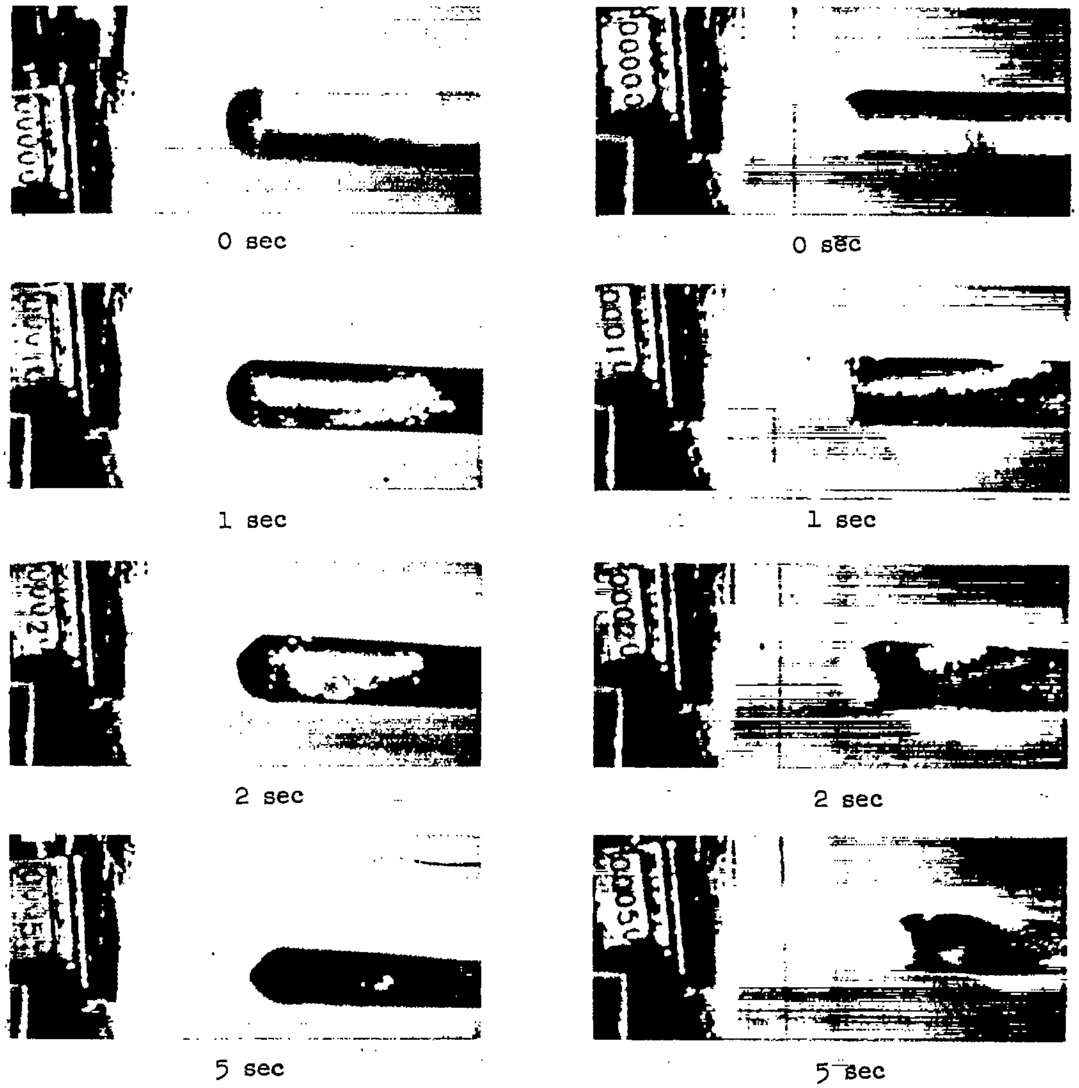
1 sec

2 sec

5 sec

L-57-44

Figure 10.- Photographs of the nylon fabric and phenolic resin (model 9) in the ceramic-heated air jet. $T_s = 3,000^\circ$ F.



(a) $T_s = 3{,}000^\circ$ F. (b) $T_s = 4{,}000^\circ$ F. L-57-4415

Figure 11.- Photographs of the vulcanized fiber (model 8) in the ceramic-heated air jet.

NACA - Langley Field, Va.

[redacted]