RM L57K22

NACA RM L57K22

NACA

RESEARCH MEMORANDUM

FEASIBILITY OF NOSE-CONE COOLING BY THE UPSTREAM EJECTION OF SOLID COOLANTS AT THE STAGNATION POINT

By William H. Kinard

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

March 24, 1958
Declassified February 8, 1960

H

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

FEASIBILITY OF NOSE-CONE COOLING BY THE UPSTREAM EJECTION OF SOLID COOLANTS AT THE STAGNATION POINT

By William H. Kinard

SUMMARY

An investigation was conducted in a chemical jet at a stagnation temperature of 4,000° F at a Mach number of 2.8 to determine the feasibility of cooling models by the ejection of a solid coolant at the stagnation point. A series of conical models with nose-cone half-angles varying from 10° to 52° were tested with glass, Lucite, nylon, Teflon, and Textolite rods as coolants.

All the coolants tested with the exception of Teflon maintained the surface temperature of the models below 1,200° F. The Teflon apparently offered less cooling to the models than did the other solids investigated because of its slow rate of vaporization.

INTRODUCTION

For a long-range ballistic missile to survive reentry it is evident that some mechanism must be employed to protect the missile from the heat generated during reentry. One possible solution to the problem of survival given in reference 1 is to equip the missile with a thick skin capable of absorbing the heat input; however, this may inflict a severe weight penalty. Another possible solution to the problem is to employ some type of cooling for the missile.

The use of a solid-type coolant may have many advantages over liquid or gaseous coolants in that the problem of storage of the coolant in the missile is simplified and no piping and pump are necessary to supply the coolant to the surface to be cooled. The solid coolant can possibly be ejected by a simple feed mechanism.

For a material to be useful as a solid coolant for models in high-temperature environments, several properties are highly desirable. First, it is desirable that the material have a low thermal conductivity to insure that the material melts or vaporizes only on the surface rather than inside the model, as the latter condition makes ejection difficult. Second, it is desirable that the material either sublimes or has a sharp melting point rather than becoming plastic and having portions of material washed away by the jet stream. In principle, the coolant material should either melt or vaporize, depending on the properties of the particular coolant material used, and the molten or vaporized material should flow back over the model surface, forming a relatively cool film which should insulate the model surface from the high jet temperature.

Several readily available materials which seemed to possess desirable properties were used for this study. No attempt was made to find a solid coolant which had ideal characteristics.

MODELS, TESTS, AND DATA REDUCTION

A schematic diagram of a solid-coolant model with a solid-coolant rod extended, the model sting, and the mechanism used to feed the coolant rods during the tests conducted in this investigation is shown in figure 1. The feed mechanism was employed so as to maintain a fixed length of the coolant rod in front of the model as the front ablated.

Sketches of the model configurations tested are shown in figure 2. All models were made of 303 stainless steel, and the type and diameter of coolant rod used, the coolant feed rate, and the test duration of each model are listed in table I. Model 9 was uncooled and had a 5/16-inch-diameter stainless-steel rod extending 1/4 inch out of the front to duplicate the geometry of the coolant rods used in the other models.

All models were tested in the supersonic chemical jet located at the Langley Aeronautical Laboratory. This facility (shown in fig. 3) is a liquid-propellant rocket motor that uses red fuming nitric acid as the oxidizer and anhydrous ammonia as the fuel. A detailed description of the facility can be found in the appendix of reference 2. During the test the rocket motor was run approximately at stoichiometric conditions.

The Mach number 2.8 jet produced by the facility had a calculated stagnation temperature of approximately 4,000° F.

The feed mechanism used to eject the solid coolant during the test, shown in figures 1 and 3, consists of a small electric motor driving a lead screw which, in turn, causes an internally threaded sleeve to advance and push the coolant out. The motor and lead screw are mounted so that they are free only to rotate. The internally threaded sleeve is free to move forward and rearward in the mechanism but is not free to rotate; thus, as the lead screw rotates, the sleeve is screwed forward or rearward, depending on the direction of rotation.

The feed-mechanism drive motor was remotely controlled by an operator who visually determined the amount of feed necessary to maintain the coolant rod approximately 1/4 inch in front of the models. The mechanism could feed the coolant at one speed only; and as the coolant rod melted back approximately 1/8 inch, the operator started the feed until the rod again extended approximately 1/4 inch in front of the models. The average coolant feed rates of the tests were determined by measuring the contour of the coolant rods in enlarged motion pictures. Table I lists the feed rates of the various coolants tested.

RESULTS AND DISCUSSION

As shown in figure 4, the glass coolant rod used in model 6 remained in the jet for approximately 1 second before any noticeable change took place. The front 1/8 inch of the glass rod then became plastic and mushroomed. No molten glass could be seen flowing back on the model face as glass apparently vaporized and the vapor flowed back.

As shown by the photographs in figure 5, the nylon coolant rods used in models 1, 3, and 4 began melting almost immediately upon being placed in the test jet and the molten nylon flowed back 1/4 to 1/2 inch along the model face before it became vaporized. After about 4 seconds in the jet the nylon rods began necking down inside the model and exposed the sharp edge of the center hole.

The Lucite rod used as the coolant for model 2 showed no sign of melting, but vaporized and thus vapor cooled the model. The Lucite behaved similar to the nylon by necking down inside the model. (See fig. 6.)

The Textolite coolant rod tested in model 8 melted similar to the nylon rod; however, the molten Textolite vaporized before it could flow back on the model surface. It also necked down similar to the nylon and Lucite.

The Teflon rod used as the coolant in model 5 failed to vaporize fast enough to cool the model as much as the other coolants investigated. Model 5 began glowing red after remaining in the test jet for about 7 seconds and thus indicated a temperature in excess of 1,200° F; however, model 5 suffered little damage during the test as evidenced by the photograph in figure 6 of the model after being tested.

The photograph in figure 6 of model 7 after being tested shows considerable damage to the leading edge; however, this damage was not inflicted to the model by the test jet. During removal from the jet, the model became loose on the sting, slid forward, and struck the rocket-motor nozzle. All other models tested with solid coolants in this investigation received no damage during the test as evidenced by their photograph in figure 6 after testing.

Model 9 was tested with no coolant to illustrate the damage inflicted by the rocket jet to an unprotected model. Figure 7 shows photographs of the model during the testing, and a photograph of the model after testing is also included in figure 6.

Of the various shapes tested with solid coolants, no one appeared to be of greater value than the others. As can be noted by the photograph in figure 8 of each model, after remaining in the jet 4 seconds, all cooled models were below red heat (1,200° F) while model 9, which was uncooled, had started to glow after 4 seconds and it began to melt shortly thereafter.

It can be noted from table I that the mass rate of ablation of the 5/16-inch-diameter nylon rods was only about 70 percent of that of the 1/2-inch-diameter nylon rods.

The rate that a solid-coolant rod can be fed out is entirely dependent upon the ablation rate of the coolant material if the coolant rod is to remain extended a constant distance. In order to vary the mass of coolant to be consumed, something must be done to affect the heat transfer and consequently the rate of ablation.

The coolant-rod diameter would probably be the simplest factor to change to vary the coolant consumption rate. This investigation was not complete enough to determine the effects of a wide range of rod diameters.

The length of coolant rod maintained in front of the model should also affect the rate of ablation by varying the surface area exposed; however, this possible influence was not investigated in these tests.

CONCLUDING REMARKS

An investigation conducted to determine the feasibility of cooling models by the upstream ejection of a solid coolant at the stagnation point proved the scheme to be promising. All the coolants tested with the exception of Teflon maintained the surface temperature of the models below 1,200° F. The Teflon was apparently less effective because of its slow rate of vaporization.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 29, 1957.

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. Fields, E. M., Hopko, Russell N., Swain, Robert L., and Trout, Otto F., Jr.: Behavior of Some Materials and Shapes in Supersonic Free Jets at Stagnation Temperatures Up to 4,210° F, and Descriptions of the Jets. NACA RM L57K26, 1958.

TABLE I.- COOLANTS USED AND TEST DURATION

Model	Diameter of coolant rod, in.	Coolant	Coolant feed rate, lb/sec	Test duration, sec
1	5/16	Nylon	0.0005	10.30
2	5/16	Lucite	.0005	8.44
3	1/2	Nylon	.00071	11.57
4	5/16	Nylon	.0005	9.69
5	5/16	Teflon	--------	9.48
6	1/4	Glass	.000043	10.64
7	1/2	Nylon	.0007	11.39
8	3/8	Textolite	.0004	10.66
9		None	--------	13.00

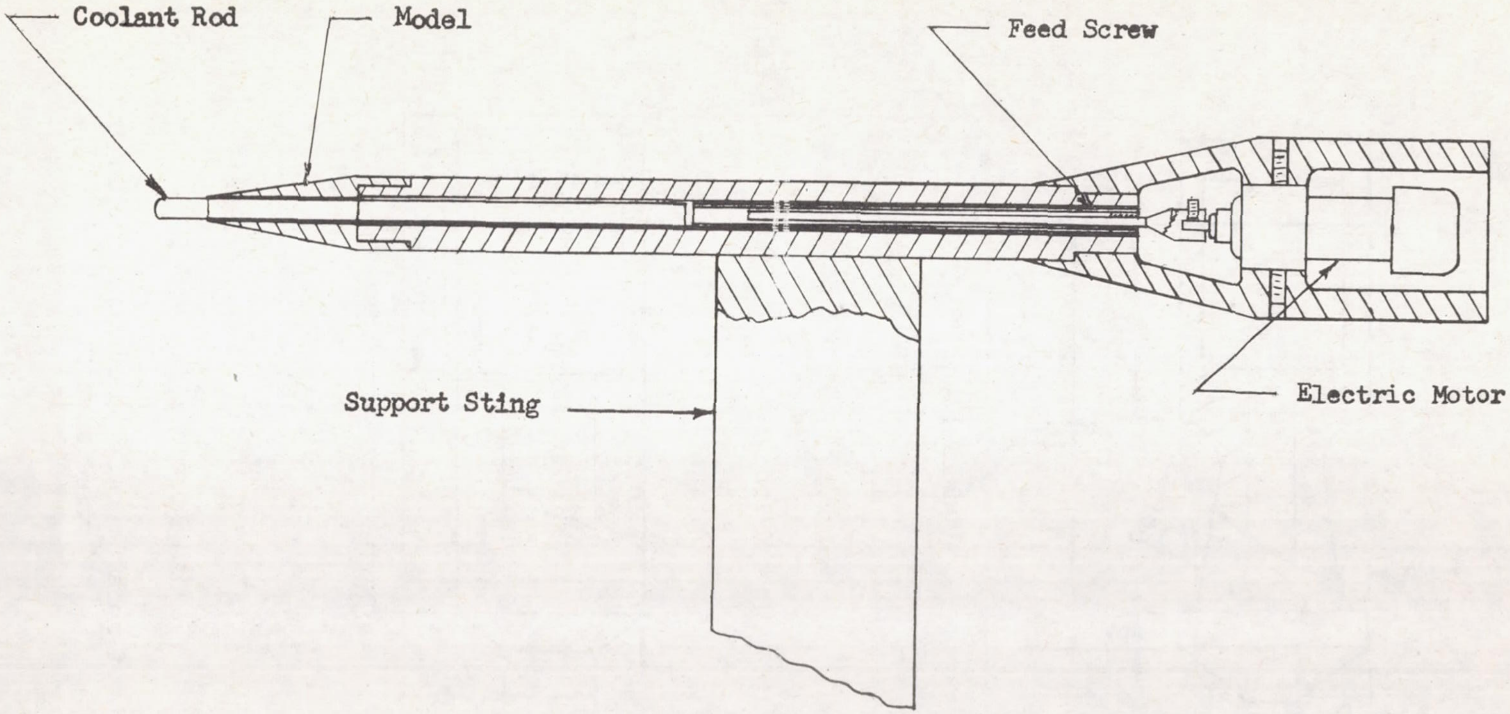
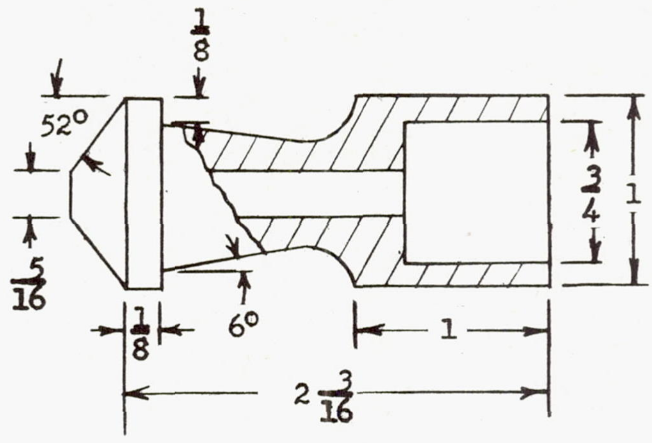
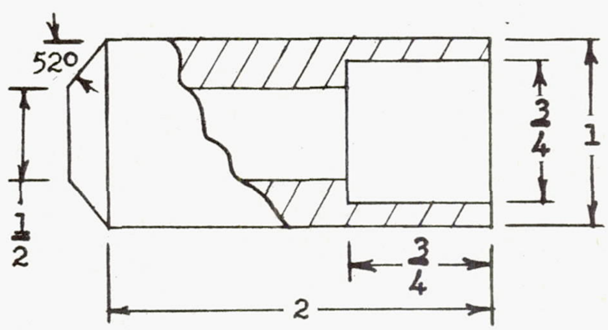


Figure 1.- Sketch of model with solid-coolant feed mechanism.



Models 1 and 2

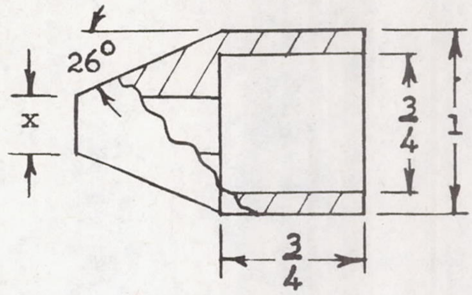


Model 3

(a) Models 1, 2, and 3.

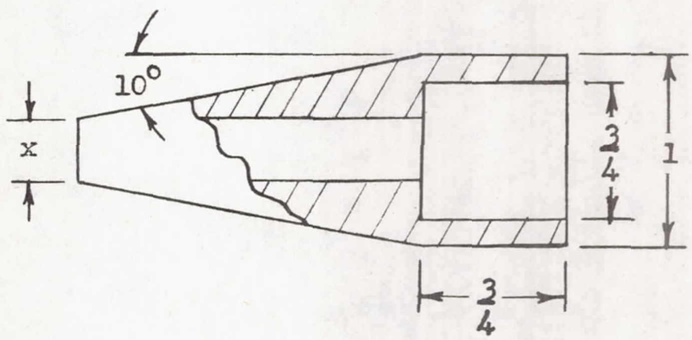
Figure 2.- Sketch of models. All dimensions are in inches unless otherwise specified.

x Dimension	
Model	x
4	5/16
5	5/16
6	1/4



Models 4, 5, and 6

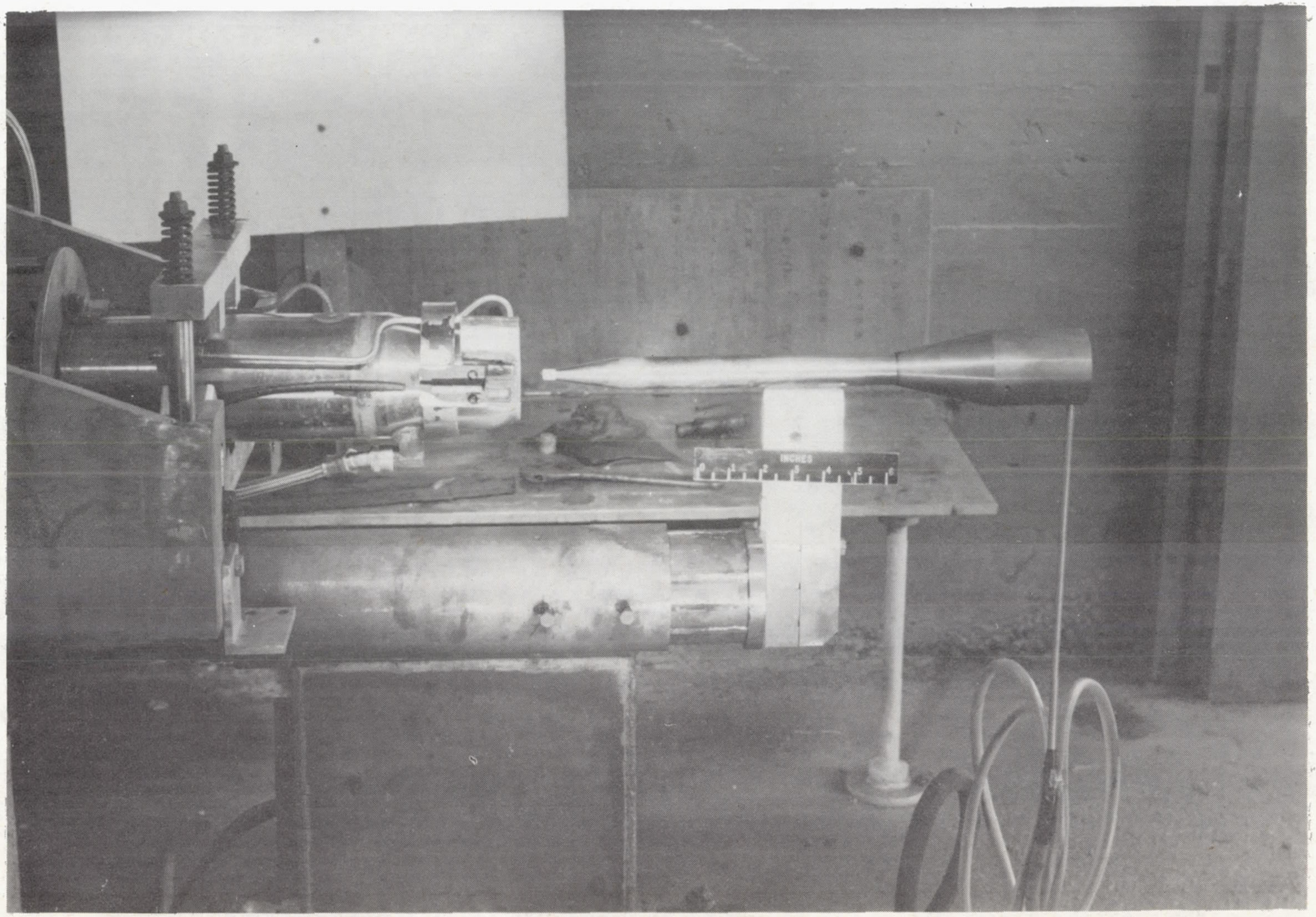
x Dimension	
Model	x
7	1/2
8	3/8
9	5/16



Models 7, 8, and 9

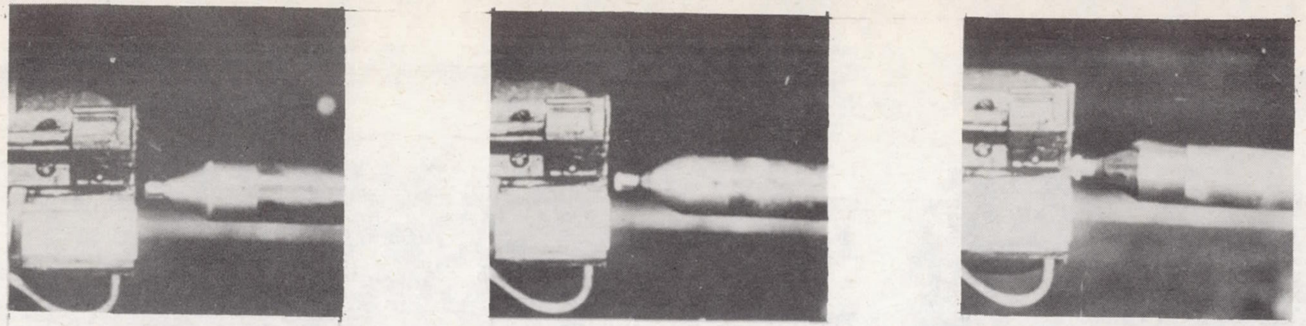
(b) Models 4 to 9.

Figure 2.- Concluded.



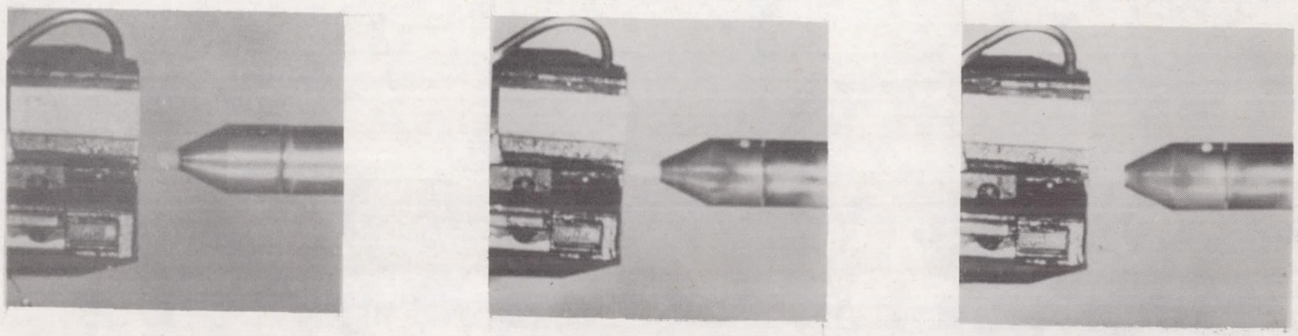
L-57-99

Figure 3.- Supersonic chemical jet with test model and solid-coolant feed mechanism mounted in test position.



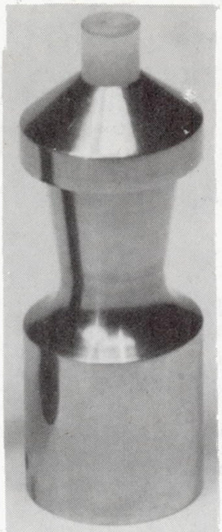
Time in jet - 0 sec 0.9 sec 2.8 sec

Figure 4.- Glass coolant rod mushrooming during test of model 6.



Time in jet - 0 sec 4.7 sec 6.5 sec

Figure 5.- Nylon coolant rods necking down during test. L-57-4416

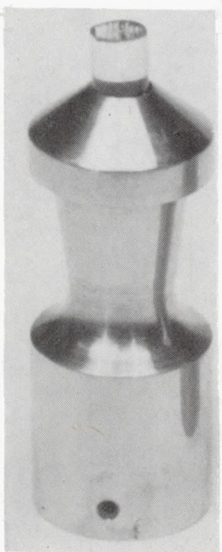


Nylon Cooled

Before test

After test

Model 1



Lucite Cooled

Before test

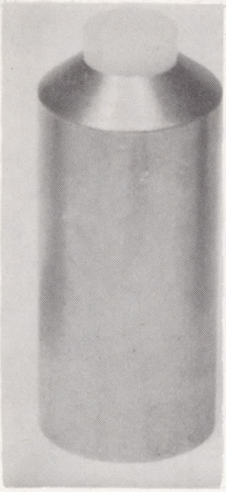
After test

Model 2

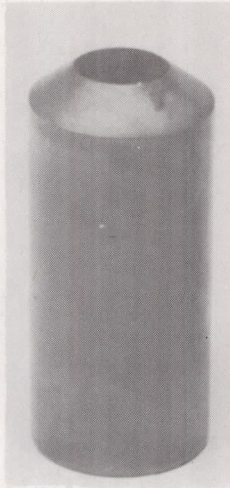
(a) Models 1 and 2.

Figure 6.- Models tested.

L-57-4417



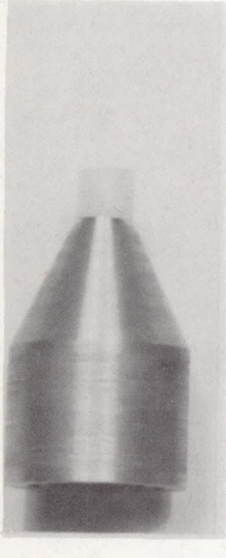
Nylon Cooled



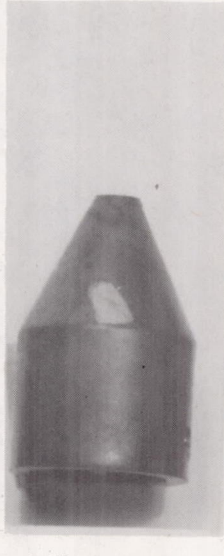
Before test

After test

Model 3



Nylon Cooled



Before test

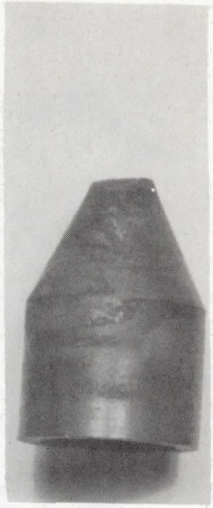
After test

Model 4

(b) Models 3 and 4.

Figure 6.- Continued. L-57-4418

Teflon Cooled



After test

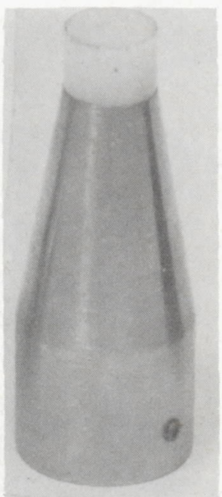
Model 5

Glass Cooled

After test

Model 6

Nylon Cooled



Before test

After test

Model 7

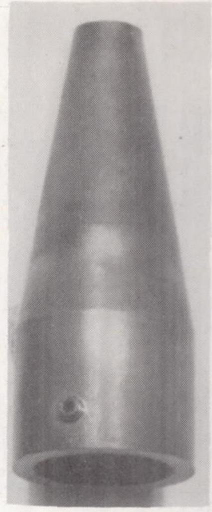
(c) Models 5, 6, and 7. Model 7 was not damaged during the test; damage occurred by model striking jet exit after test.

Figure 6.- Continued. L-57-4419

Textolite Cooled

After test

Model 8



No Coolant

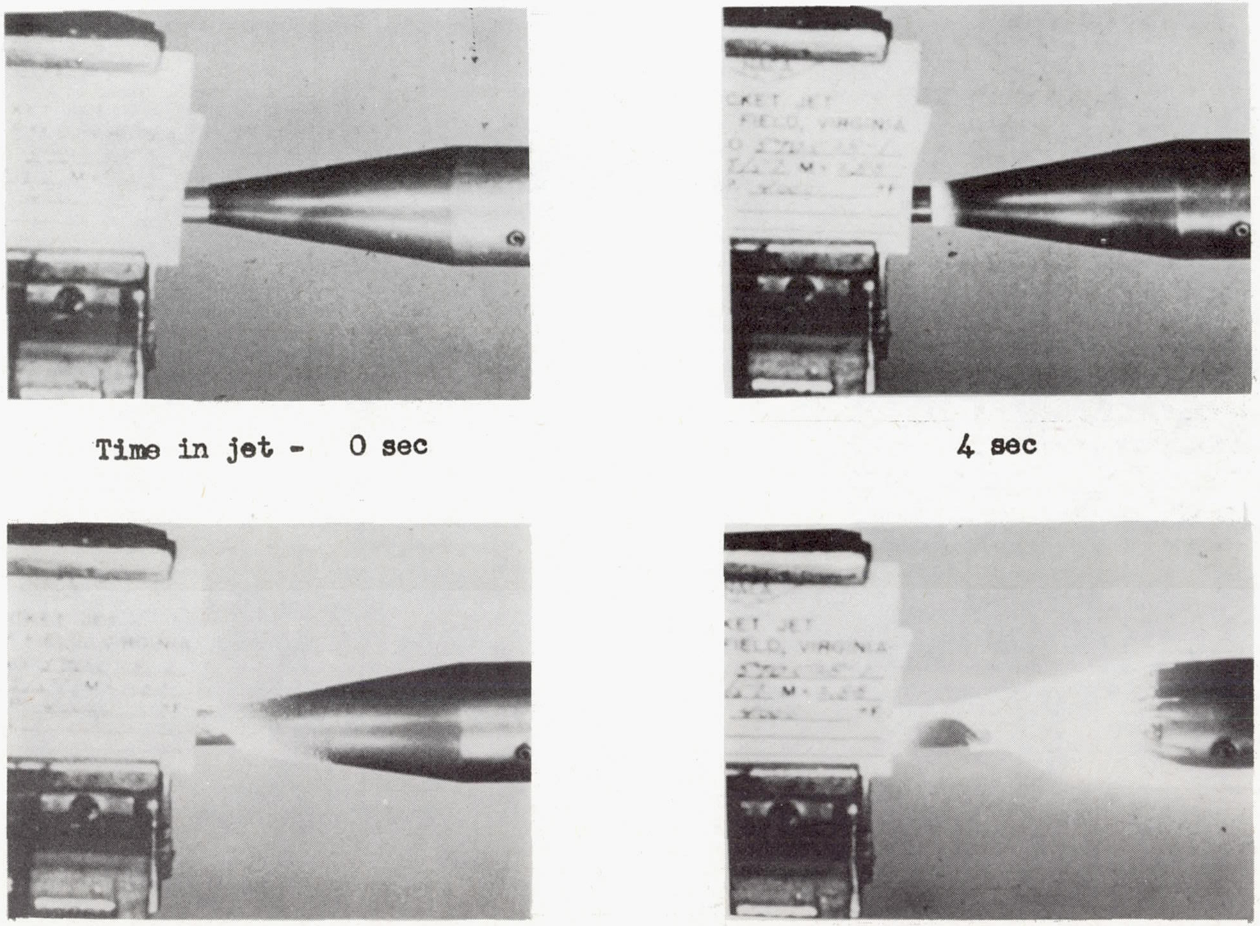
Before test

After test

Model 9

(d) Models 8 and 9.

Figure 6.- Concluded. L-57-4420



Time in jet - 0 sec

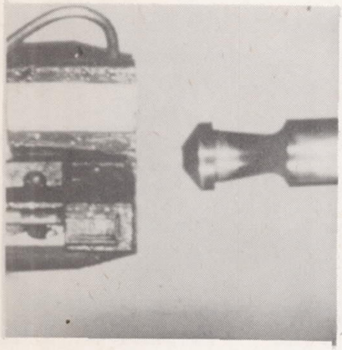
4 sec

Time in jet - 6 sec

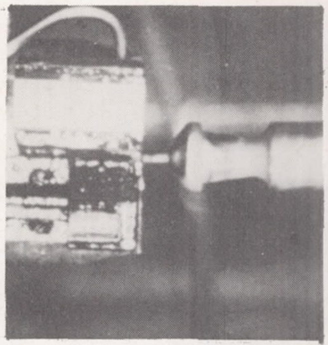
10 sec

L-57-4421

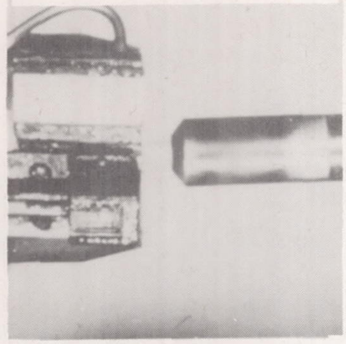
Figure 7.- Uncooled model 9 in supersonic chemical jet at 4,000° F.



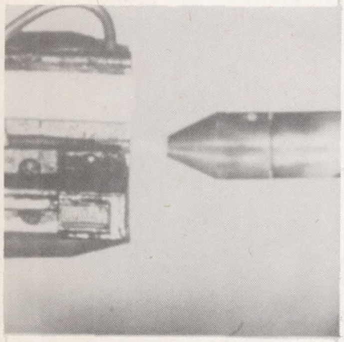
Model 1
Coolant - Nylon



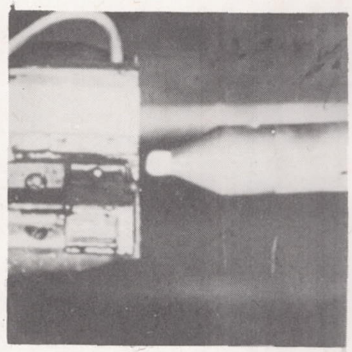
Model 2
Coolant - Lucite



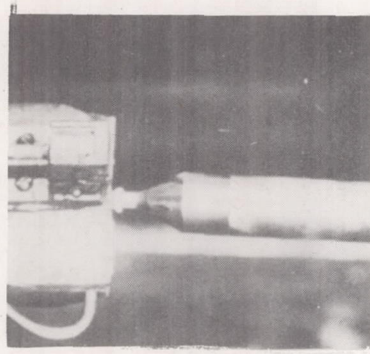
Model 3
Coolant - Nylon



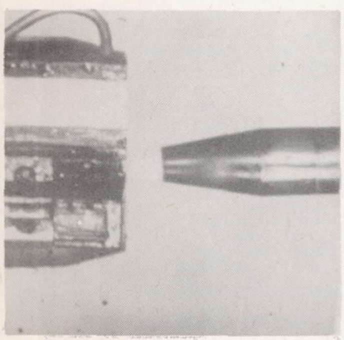
Model 4
Coolant - Nylon



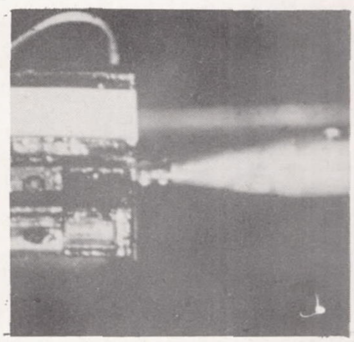
Model 5
Coolant - Teflon



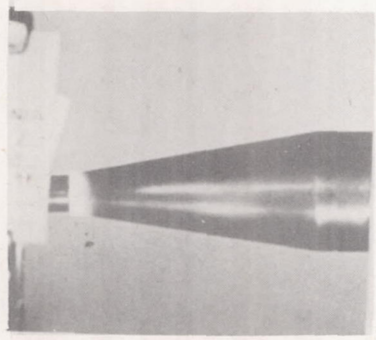
Model 6
Coolant - Glass



Model 7
Coolant - Nylon



Model 8
Coolant - Textolite



Model 9
Coolant - None

L-57-4422

Figure 8.- Models after remaining in supersonic chemical jet for 4 seconds.