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A Limited Study of the Effect of Airflow on Hot-Surface Ignition Temperatures of Several Aircraft Flammable Fluids

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by

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A LIMITED STUDY OF THE EFFECT OF AIRFLOW ON HOT-SURFACE IGNITION TEMPERATURES OF SEVERAL AIRCRAFT FLAMMABLE FLUIDS

SUMMARY

Aviation gasoline, JP-4 fuel, hydraulic fluid, and two turbine engine lubricants were sprayed over a heated metal surface in a duct through which airflow was induced at a varied rate. When the surface of the metal reached specific temperatures, the fluids became ignited. The minimum surface temperature at which ignition occurred for each fluid was recorded for air velocities from 0 to 1,000 feet per minute. Two series of tests were conducted. A length of stainless steel tubing was used for the heated section in the first series and a flat metal sheet was used in the second series. The lowest surface temperatures which caused ignition were observed when tests were conducted under static air conditions. Movement of the combustible mixtures by airflow across the heated surfaces required higher temperature for ignition to occur.

INTRODUCTION

Knowledge of the effect of airflow on the temperature at which engine surfaces and components, when contacted by fuel, lubricants, and hydraulic fluids, will cause these fluids to ignite is of increasing importance since recent aircraft powerplant design trends eliminate separation of the nacelle zones adjacent to the forward and rear portions of turbine engines. This allows the air required for engine cooling to enter at the front of the engine nacelle and flow along the entire length of the engine and exit at the rear of the nacelle. Fluids leaking in the forward portion of the engine are carried by the cooling air across the high-temperature engine surfaces at the rear portion of the engine. Therefore, tests were conducted to study the effect of airflow on the temperatures at which certain metal surfaces become a source of ignition for several flammable fluids. The scope of the tests was limited since only two surface shapes were used and these were small in size. Also, the air velocity range was limited from approximately 0 to 1,000 feet per minute. The effects of fuel-air ratio, fuel temperature, hot-surface material used, air density or other variables that may influence the ignition temperature were not investigated.

APPARATUS AND PROCEDURE

The apparatus used to conduct the first series of tests is shown in Fig. 1. A variable speed fan was used to force air at room temperature (70° to 90° F.) and pressure (approximately 29.3 inches Hg) through the transite duct which was 8 feet long and 12 inches i.d., with a 3/8-inch wall thickness. The heated section of 18-8 stainless steel tubing was 2 1/2 inches o.d., 8 inches long, and had a wall thickness of 0.070-inch. Uniform heating was accomplished by using a 50-Kva transformer with its secondary terminals attached to ends of copper bars pressed 2 inches into each end of the stainless steel tubing The resistance of the remaining 4 inches of the steel tubing to passage of current caused it to become heated. The temperature of the heated section was controlled by adjusting the input to the transformer by a salt water rheostat. A Brown radiomatic pyrometer was used to measure the metal temperatures, and an Alnor velometer was used to measure the velocity of the air leaving the duct. A No. 32 Bette nozzle was used to spray the fluids into the duct. Twenty cc. of fluid was released during a 0.6-second period for each test. No attempt was made to obtain ideal mixing of fuel and air; rather, a quantity of fuel was sprayed in a manner to simulate a leaking fuel, oil, or hydraulic fluid line in a region between an aircraft turbine engine and the nacelle skin.

The apparatus used to conduct the second series of tests was the same as was used for the first except that a flat plate of 18-8 stainless steel was used for the heated surface in place of the 2 1/2-inch o.d. tubing. The plate was 4.0 inches by 6.29 inches by 0.062-inch thick and was mounted with the 4-inch edge facing upstream. This plate, as viewed from the outlet end of the duct, is shown in Fig. 2.

The tests for each fluid were conducted first with no airflow through the duct, and then at varied rates of airflow. The heated section then was brought up to the desired temperature and stabilized. At this time, the sample of fuel was released and allowed to spray on the heated surface. The temperature of the heated section was increased in increments of 50° F. until the test fluid ignited. Several tests were conducted to confirm the ignition temperature of the fluid for that particular airflow condition. After each test the equipment was allowed to cool to room temperature before proceeding with the next test.

RESULTS AND DISCUSSION

Graphical presentations of the data obtained are shown in Figs. 3 and 4. Since the tests were conducted in 50° F. increments of surface temperature, the curves represent the lowest temperature increments at which ignition occurred under each set of airflow conditions. The air velocities shown are the speed of the air at the exit of the duct and not necessarily that of the layer of air next to the heated surfaces.

From these data, it may be noted that the lowest surface temperatures which caused ignition occurred under the condition of no airflow through the duct. When air was flowing through the duct, the temperatures required for ignition were found to be higher. The greatest rate of increase of the temperature required for ignition occurred between conditions of no airflow and an airflow rate of about 200 feet per minute. Above 200 feet per minute, the temperature required did not increase quite so rapidly with increased airflow.

This relation between air velocity and minimum ignition temperature must be explained by some phenomenon other than the cooling effect of the air moving over the hot surface, since airflow and temperature conditions were stabilized prior to release of fluid spray. It has been found in several investigations, discussed in the references at the end of this report,[1, 2, 3, 4, 5] that the autogenous ignition temperature (AIT), also called the spontaneous ignition temperature (SIT), is always accompanied by an ignition time lag. For any one substance being heated, the net amount of heat absorbed is increased as the temperature of the source is increased. Also, it is definitely known that the ignition lag is decreased as the initial temperature of the fluid is increased. Because of these facts, it was concluded in a report on ignition of combustible fluids,[5] in which the flammable fluid was sprayed onto the lower portion of a heated vertical flat plate so that the flammable vapors might rise along the hot surface, that the actual ignition of a combustible mixture in contact with a hot surface must be dependent on the following interrelated factors: (1) sufficiently high temperature of the combustible mixture, (2) sufficiently short ignition lag of the combustible mixture, and (3) sufficiently long duration of upward movement of the mixture along the hot surface in the region of high temperature. The rate at which molecules of the combustible mixture absorbed sufficient heat to ignite determined the duration of ignition lag of each fluid.

The rapid increase in ignition temperature when the initial air was introduced may be explained by the fact that the mixture was not in contact with the hot surface for a sufficient period of time to permit accelerating the oxidation reaction to ignition, making it necessary to decrease the ignition lag by increasing the temperature of the hot surface.

Also, it may be noted from the data that the minimum ignition temperatures on the flat plate were somewhat lower than they were on the section of the tubing, although the effect of airflow on ignition temperature was similar for both surfaces. This may be explained by the fact that the flat plate presented a greater area of contact to the combustible mixture along the direction of airflow than did the section of heated tubing. This provided a longer duration of movement of the combustible mixture in the region of high temperature.

CONCLUSIONS

1. The minimum temperature of a hot surface which will cause ignition of a flammable fluid increases as the air velocity across the surface is increased. All fluids tested behaved similarly. This increase in the surface temperature required for ignition as the air velocity increased is related to the ignition time lag characteristics of flammable fluids.

2. These tests were too limited in scope for the data to be interpreted as an indication of the maximum safe engine surface temperature for prevention of flammable fluid ignition in aircraft powerplant regions.

REFERENCES

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4. G. W. Jones, M. G. Zabetakis, G. S. Scott, and A. L. Furns, "Research on the Flammability Characteristics of Aircraft Fuels," WADC Technical Report No. 52-35, Supplement 2, August 1954.

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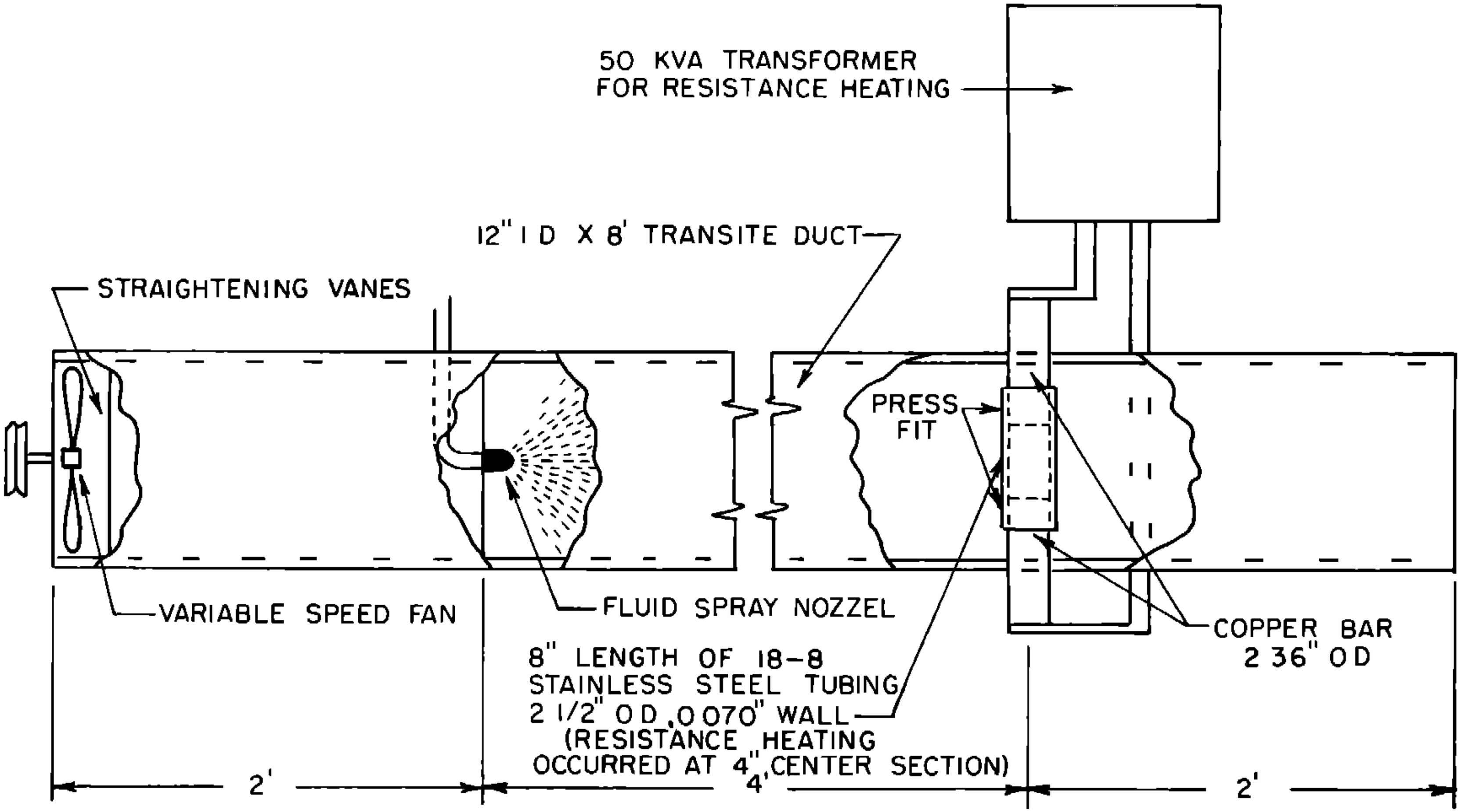

FIG 1 TEST APPARATUS

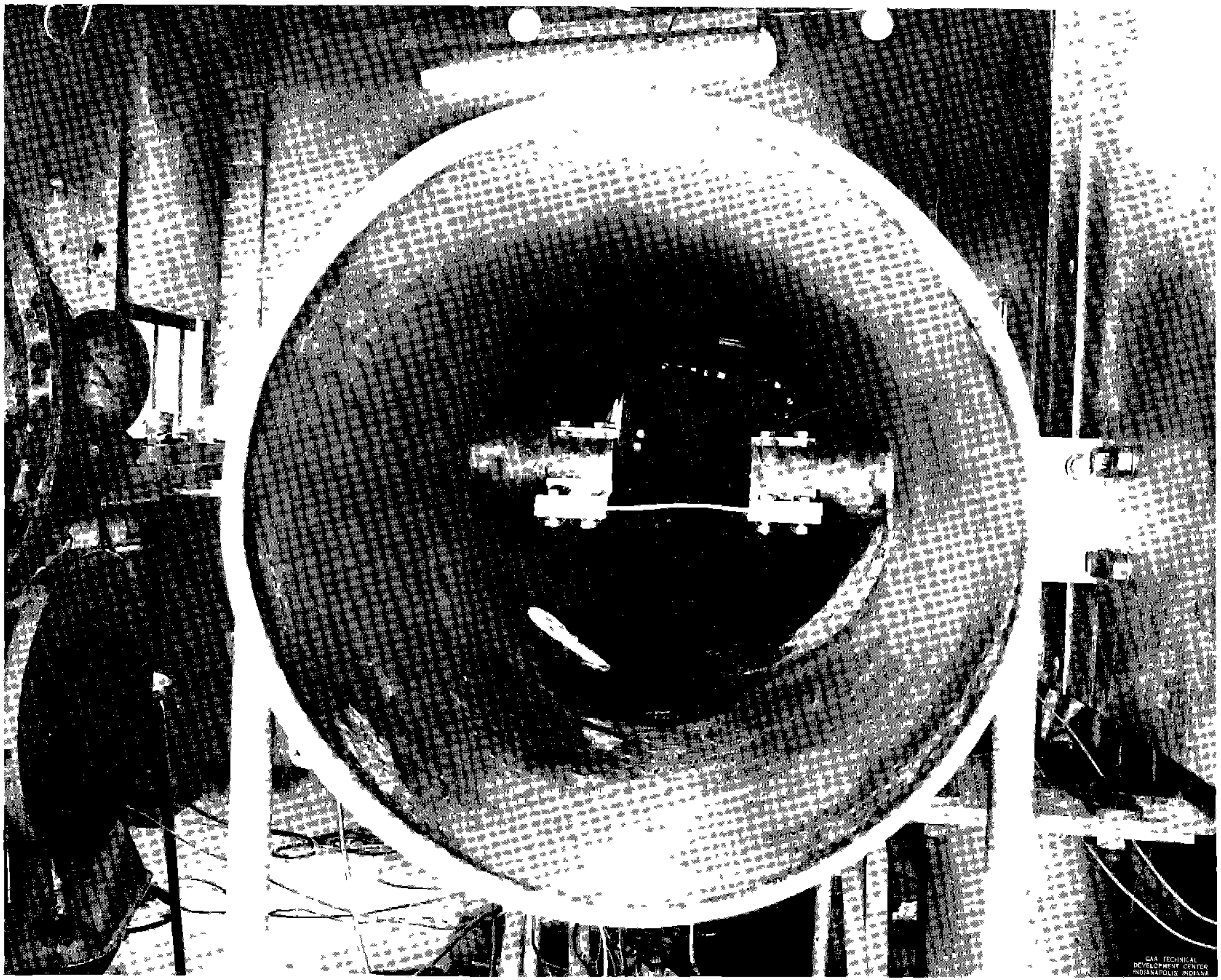

FIG 2 VIEW OF SHEET METAL TEST SURFACE

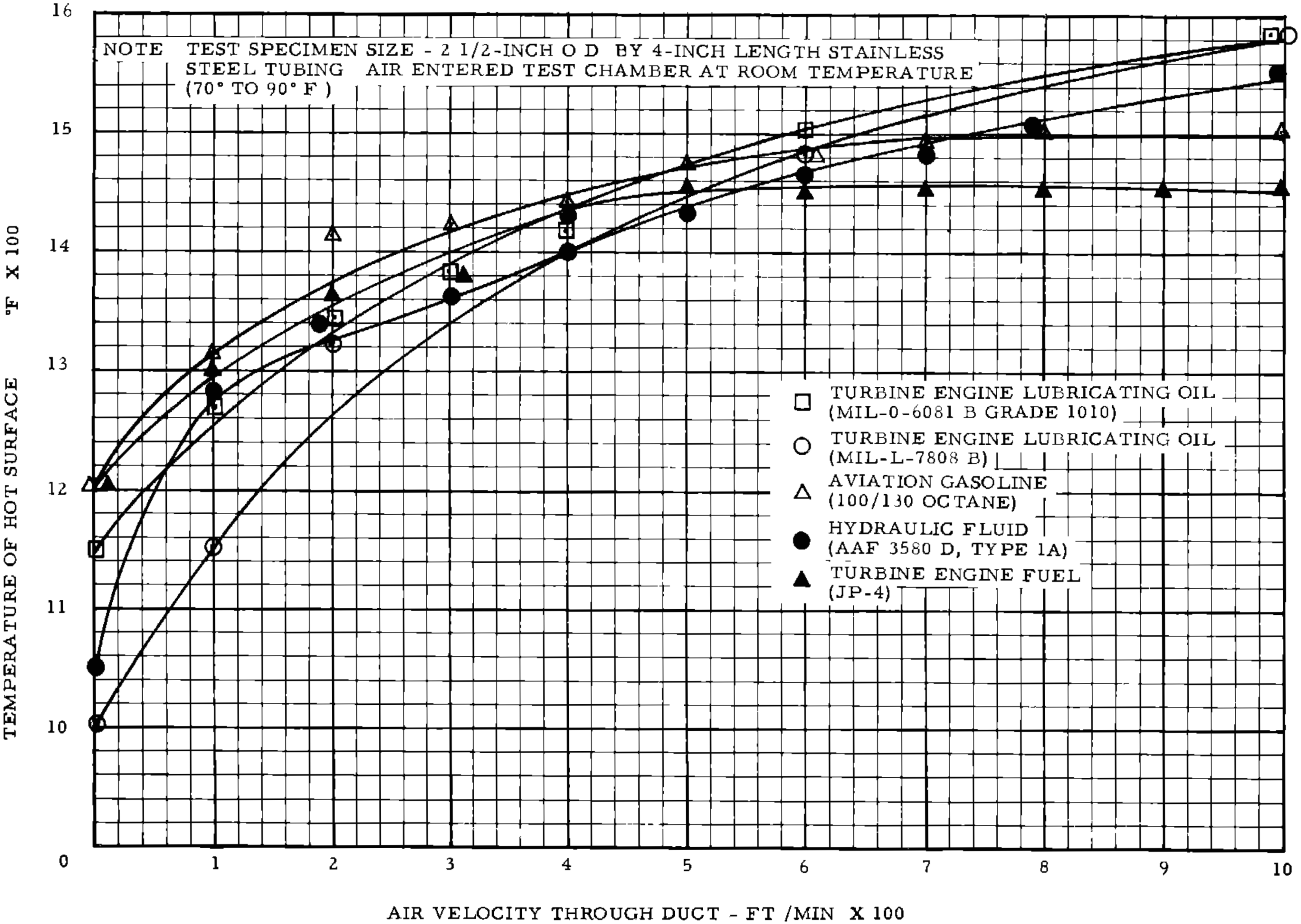

FIG 3 MINIMUM TEMPERATURE OF HEATED SECTION OF TUBING WHICH CAUSED FLAMMABLE FLUIDS TO IGNITE UNDER VARIOUS AIRFLOW CONDITIONS IN DUCT

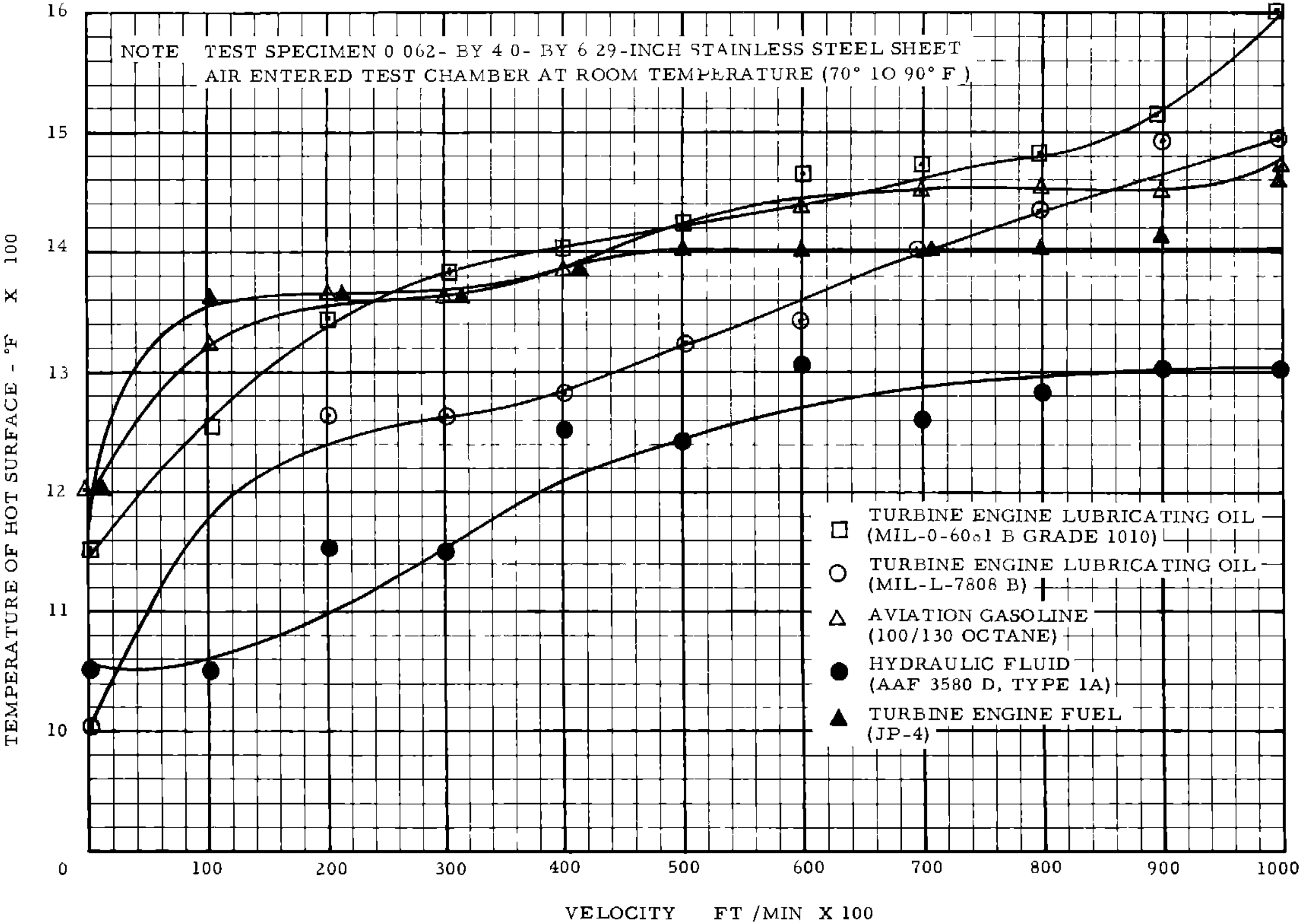

FIG 4 MINIMUM TEMPERATURE OF HEATED FLAT SURFACE WHICH CAUSED FLAMMABLE FLUIDS TO IGNITE UNDER VARIOUS AIRFLOW CONDITIONS IN DUCT