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RESEARCH MEMORANDUM

EFFECT OF FUEL ON PERFORMANCE OF A SINGLE COMBUSTOR OF AN I-16 TURBOJET ENGINE AT SIMULATED ALTITUDE CONDITIONS

By Eugene V. Zettle, Ray E. Bolz, and R. T. Dittrich

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EFFECT OF FUEL ON PERFORMANCE OF A SINGLE COMBUSTOR OF AN I-16 TURBOJET ENGINE AT SIMULATED ALTITUDE CONDITIONS

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SUMMARY

As part of a study of the effects of fuel composition an inves- atility on the combustor performance of a turbojet engine, and inves tigation was made in a single I-16 combustor with the standard I-16 injection nozzle, supplied by the engine manufacturer, at simulated altitude conditions.

The 10 fuels investigated included hydrocarbons of the paraffin olefin, naphthene, and aromatic classes having a boiling range from 113° to 655° F. They were hot-acid octane, diisobutylene, methyl-cyclohexane, benzene, xylene, 62-octane gasoline, kerosene, solvent solvent 2, and Diesel fuel oil. The fuels were tested at combustor conditions simulating I-16 turbojet operation at an altitude of 45,000 feet and at a rotor speed of 12,200 rpm. At these conditions the combustor-inlet air temperature, static pressure, and velocity were 60° F, 12.3 inches of mercury absolute, and 112 feet per second, respectively, and were held approximately constant for the investigation. The reproducibility of the data is shown by check runs take each day during the investigation. The combustion in the exhaust elbow was visually observed for each fuel investigated.

When no attempt was made to adjust the fuel-spray-tip design to compensate for differences in the properties of the fuels, the combustion efficiency of the combustor decreased with an increase in fuel boiling point, particularly in the range of low heat inputs. The efficiency was relatively unaffected by differences in the hydrocarbon type for the fuels investigated except for aromatic fuels, which exhibited somewhat lower efficiencies than the other classes.

INTRODUCTION

A program to investigate the effects of fuel volatility and hydrocarbon type on turbojet-engine performance and to obtain data that may be useful for establishing effective turbojet-fuel specifications has been instituted at the NACA Cleveland laboratory. In the first part of this program (reference 1), 14 fuels were investigated in a full-scale I-16 turbojet engine at static sea-level conditions. The results indicated that neither the hydrocarbon type nor the volatility of the fuels had any appreciable effects on the combustion efficiency of the combustors or on the thrust of the engine at static sea-level operation.

The data of the present report show the effect of hydrocarbon type and fuel volatility on the combustion efficiency of a single combustor at simulated high-altitude conditions (45,000 ft and an engine speed of 12,200 rpm) preselected to subject the combustor to a severe test. Performance characteristics investigated were combustion efficiency and pressure loss. The 10 fuels investigated included fuels representing paraffin, olefin, naphthene, and aromatic classes of hydrocarbons, as well as a wide range of boiling points, in order that the effect of both hydrocarbon type and volatility could be evaluated. This investigation is preliminary in an over-all fuel program for turbojet engines and serves to indicate the direction that future research should take. Characteristics such as carbon deposition and smoke density were not investigated. No attempt was made to accommodate the fuel-spray-tip design to either the various fuels or the wide range of fuel-air ratios encountered.

FUELS

Data on the physical properties of the 10 fuels investigated are given in table I. Hot-acid octane, diisobutylene, methylcyclohexane, and benzene are representative of the four general classes (paraffin, olefin, naphthene, and aromatic) of hydrocarbons in the gasoline boiling range. Benzene and xylene represent two pure aromatic fuels having different boiling points (170° – 278° F). Kerosene, 62-octane gasoline, solvent 1, solvent 2, and Diesel fuel oil are five mixed hydrocarbon fuels presenting a wide range of boiling points (113° – 655° F). Solvent 2 is a heavy kerosene cut with essentially all the aromatics removed. Solvent 1 is a light kerosene cut with the aromatics removed.

EQUIPMENT

A general view of the setup is presented as figure 1. The combustor was connected to the laboratory services as diagrammatically shown in figure 2. The air supply was measured by a square-edged orifice located upstream of the inlet regulating valves. The inlet air was heated, when necessary, to the desired temperature by passin part of the air through an air preheater. The heated and unheated air was mixed by two butterfly valves operated with an automatic regulator. Conditions at the combustor inlet were controlled by manually adjusting the appropriate valves in the inlet and outlet ducts. Fuel flow was measured with a rotameter, which was calibrate for each fuel investigated. A standard hollow-cone fuel-spray tip with a capacity of 21.5 gallons per hour was used in the combustor throughout the investigation.

The combustor, the inlet and outlet ducting, and the method of instrumentation are shown in figure 3. The details of the instrumentation are shown in figure 4.

Iron-constantan thermocouples were used to measure orifice and combustor-inlet temperatures. The exhaust-gas temperatures were determined by averaging the temperatures indicated by eight chromel-alumel thermocouples located in an equal-area traverse. The thermocouples were shielded from radiation by concentric metal cylinders, as shown in figure 3 (section B-B). The temperature survey was made $12\frac{1}{2}$ pipe diameters downstream of the combustor-outlet elbow in a region where a uniform gas-flow profile existed. At this location, a fairly accurate measurement of the average outlet temperature in the duct could be obtained. The outlet duct between the elbow and the temperature survey was insulated against radiation losses.

Although there was visual evidence of only slight afterburning between the turbine-nozzle section and the thermocouple station, a strict interpretation requires that the data herein be considered to apply to the performance of an I-16 combustor equipped with a 6-foot exit duct. The trends obtained for the effects of the fuel characteristics on the combustion efficiency at the end of this exit duct are believed, however, to be indicative of the effects on the combustion efficiency at the exit of the I-16 combustor proper.

PROCEDURE

The combustor-inlet air conditions for various altitudes and engine speeds for an I-16 turbojet engine, determined from an unreported investigation of this engine in the Cleveland altitude wind tunnel, are shown in figure 5. This figure was used in setting the combustor conditions for the simulated altitude and engine speed of the investigation.

The standard test for each of the 10 fuels consisted in holding the inlet-air variables of temperature, pressure, and velocity constant at a test condition simulating an altitude of 45,000 feet and a rotor speed of 12,200 rpm (inlet temperature, 60° F; inlet pressure, 12.3 in. Hg absolute; inlet velocity, 112 ft/sec) and varying the heat input over as wide a range as possible. A check run on solvent 1 was made each day to indicate the reproducibility of the data.

The temperature rise across the combustor was determined by obtaining the difference in the average temperature at stations A and B (fig. 3). The combustion efficiency as used herein is defined as the ratio of the temperature rise through the combustor to the theoretical temperature rise available from the fuel-air mixture under investigation. The theoretical temperature rise was obtained from reference 2. In order to place the performance of the various fuels having differences in heating value on a comparable basis, the combustion efficiency is plotted against heat input, where heat input is computed as the product of the fuel-air ratio and the lower heating value of the fuel. The lower heating value of the fuel must be used because all the water formed by combustion is in vapor form and therefore the heat of vaporization of the water cannot be included in the heat supplied. The theoretical curves for combustion efficiencies of 60, 80, and 100 percent were calculated for the reference fuel, solvent 1, using variable specific heats (reference 2) for the exhaust-gas products and are drawn on the performance curves for reference.

RESULTS

Combustion efficiency. - In the first experiment, the hydrocarbon type was held constant and the boiling-point range was varied by choosing two commercially pure aromatic fuels with different boiling-point ranges. The results of this experiment are shown in figure 6 where mean temperature rise is plotted against heat input. Figure 6 indicates that the combustion efficiency of the combustor decreases with an increase in fuel boiling point for fuels of the same hydrocarbon type, particularly at low heat inputs.

In the second experiment, the fuel boiling range was held approximately constant and the hydrocarbon type was varied by choosing four fuels in the gasoline boiling range representing paraffin, olefin, naphthene, and aromatic classes of hydrocarbons. The combustion efficiency of the combustor was relatively unaffected by difference in fuel hydrocarbon type except for the aromatic fuel, benzene, which shows an efficiency about 20 percent (maximum) lower than the other fuels (fig. 7). Aromatic fuels have a low hydrogen-carbon ratio and it was this type of fuel that exhibited heavy smoking tendencies in the tests of reference 1.

In order to extend the investigation to a wider range of fuels in the third test, fuels were included that differed both in hydrocarbon type and volatility. These data (fig. 8) serve to substantiate the evidence presented in figures 6 and 7 that the difference in fuel volatility have a much greater effect on the combustion efficiency of the combustor than have differences in the hydrocarbon type of the fuel.

The data of figures 6 to 8 are replotted in figure 9 to illustrate how the combustion efficiency decreases with an increase in the mean fuel boiling point (fig. 9). It is emphasized that these results relate to a single combustor and nozzle. A large part of the difference in performance of fuels shown in figure 9 might possibly be eliminated by adjusting both the combustor and the fuel-spray-tip design to compensate for the differences in fuel properti

Combustor pressure loss. - The total-pressure loss ΔP across the test section is plotted as a function of the density ratio acro the combustor ρ_1/ρ_2 in figure 10. The coordinates are expressed in dimensionless units. The total-pressure loss is shown as a fraction of an impact pressure defined by $\rho V^2/2g$ where

ρ density calculated at combustor inlet, (lb/cu ft)

V inlet velocity that would exist for inlet area equal to maxim cross-sectional area in combustor, (ft/sec)

g acceleration of gravity, 32.2 (ft/sec^2)

The results follow an approximately straight line as indicated by the theoretical analysis of a constant-cross-section duct given in reference 3. Neither hydrocarbon type nor fuel volatility influences this type of correlation; therefore, the data for all the fuels can be plotted on the same correlation curve.

Reproducibility. - A check run with solvent 1 fuel was made each day to indicate the day-to-day reproducibility of the data.

The results of these reference tests are shown in figure 11 and indicate a maximum deviation in temperature-rise data of 8 percent. The thermocouples measured a temperature somewhat lower than the stagnation temperature because of their inability to convert all of the kinetic energy into heat. The velocities were sufficiently small that the error in using the indicated temperature as a stagnation temperature is less than 1 percent.

Visual observation. - Traces of flame were noticeable at the exhaust elbow at temperatures of about 1000° to 1200° F for all fuels in the gasoline boiling range, as well as solvent 1. Flame was noticeable at a temperature of 900° F for kerosene (boiling range, 302° - 486° F) and long flashes were visible for all fuels of higher boiling points at this temperature. Solvent 2 (boiling range, 370° - 485° F) burned erratically; combustion became unstable at fuel-air ratios below 0.020. Solvent 1 (boiling range, 307° - 382° F) burned smoothly. Diesel fuel oil (boiling range, 350° - 655° F) would not ignite except at extremely low air flows; combustion was unstable and intermittent, and stable combustion was impossible at fuel-air ratios below 0.027.

SUMMARY OF RESULTS

Ten fuels were investigated in a single combustor of an I-16 engine at a simulated altitude of 45,000 feet and a simulated rotor speed of 12,200 rpm. They were hot-acid octane, diisobutylene, methylcyclohexane, benzene, xylene, 62-octane gasoline, kerosene, solvent 1, solvent 2, and Diesel fuel oil. No attempt was made to adjust the fuel-spray-tip design to compensate for differences in properties of fuels. The results indicated that the combustion efficiency of the combustor (a) decreased with an increase in fuel boiling point, and (b) was relatively unaffected by difference in the hydrocarbon type for the fuels investigated except for aromatic fuels, which exhibited somewhat lower efficiencies than the other classes.

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Cleveland, Ohio.

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2. Turner, L. Richard, and Lord, Albert M.: Thermodynamic Charts for the Computation of Combustion and Mixture Temperatures at Constant Pressure. NACA TN No. 1086, 1946.

3. Childs, J. Howard, McCafferty, Richard J., and Surine, Oakley W. Effect of Combustor-Inlet Conditions on Performance of an Annular Turbojet Combustor. NACA TN No. 1357, 1947.

TABLE I

PHYSICAL DATA AND APPROXIMATE COMPOSITION OF 10 FUELS INVESTIGATED

Fuel	Boiling range (°F)	Specific gravity at 60°/60° F	Hydrogen-carbon ratio	Lower heating value (Btu/lb)	Approximate composition (percent by volume)			
					Paraffin	Naphthene	Aromatic	Olefin
Hot-acid octane	174-257	0.715	0.188	19,200	100	0	0	0
Diisobutylene	210-216	.726	.167	19,000	0	0	0	100
Methylcyclohexane	207-212	.773	.170	18,500	0	100	0	0
Benzene	170-175	.883	.084	17,400	0	0	100	0
Xylene	273-278	.867	.106	17,600	0	0	100	0
62-octane gasoline	113-233	.699	.182	19,000	76	22	[a]1	Low
Kerosene	302-486	.809	.164	18,500	45	25	[a]14	Low
Solvent 1	307-382	.769	.174	18,800	62	36	[a]1	Low
Solvent 2	370-485	.792	.174	18,700	62	33	[a]Low	----
Diesel fuel oil	350-655	.829	.161	18,400	-----	-----	[a]19	2

[a]Analysis by emergency method of test: A.S.T.M. designation, ES-45a.

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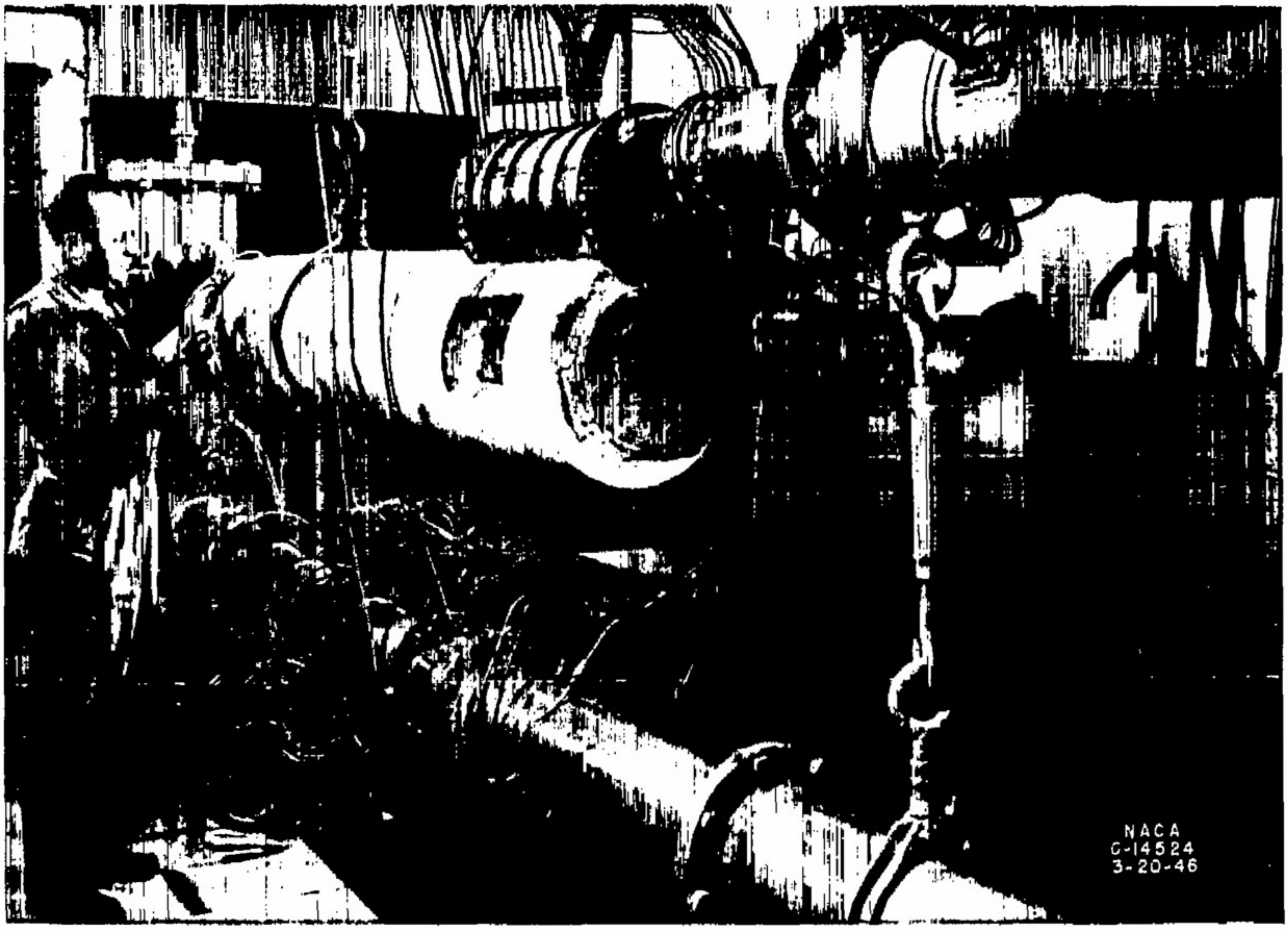

Figure 1. - Setup for fuel investigations in a single I-16 combustor.

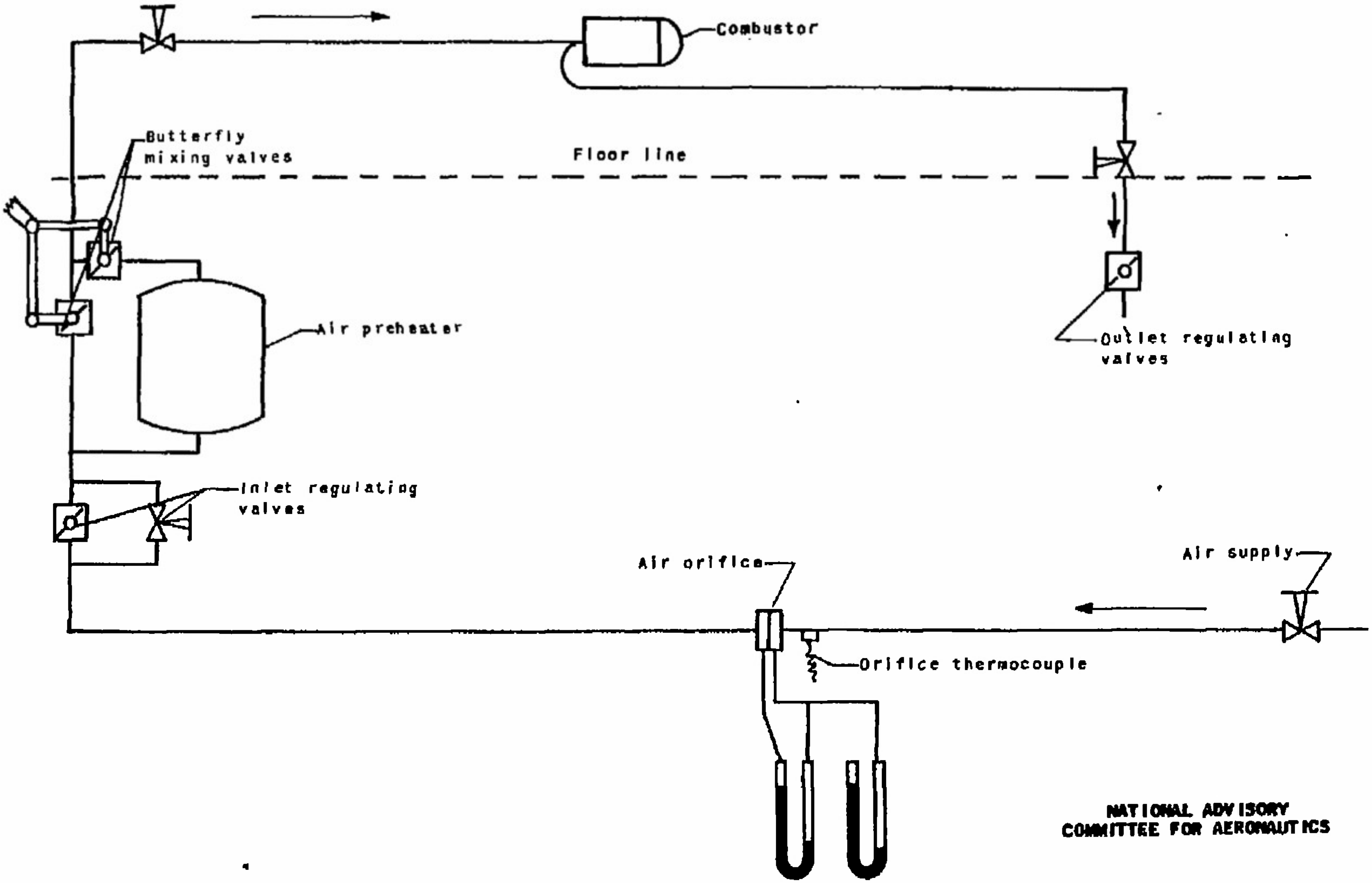

Figure 2. - Diagrammatic sketch showing air-control system.

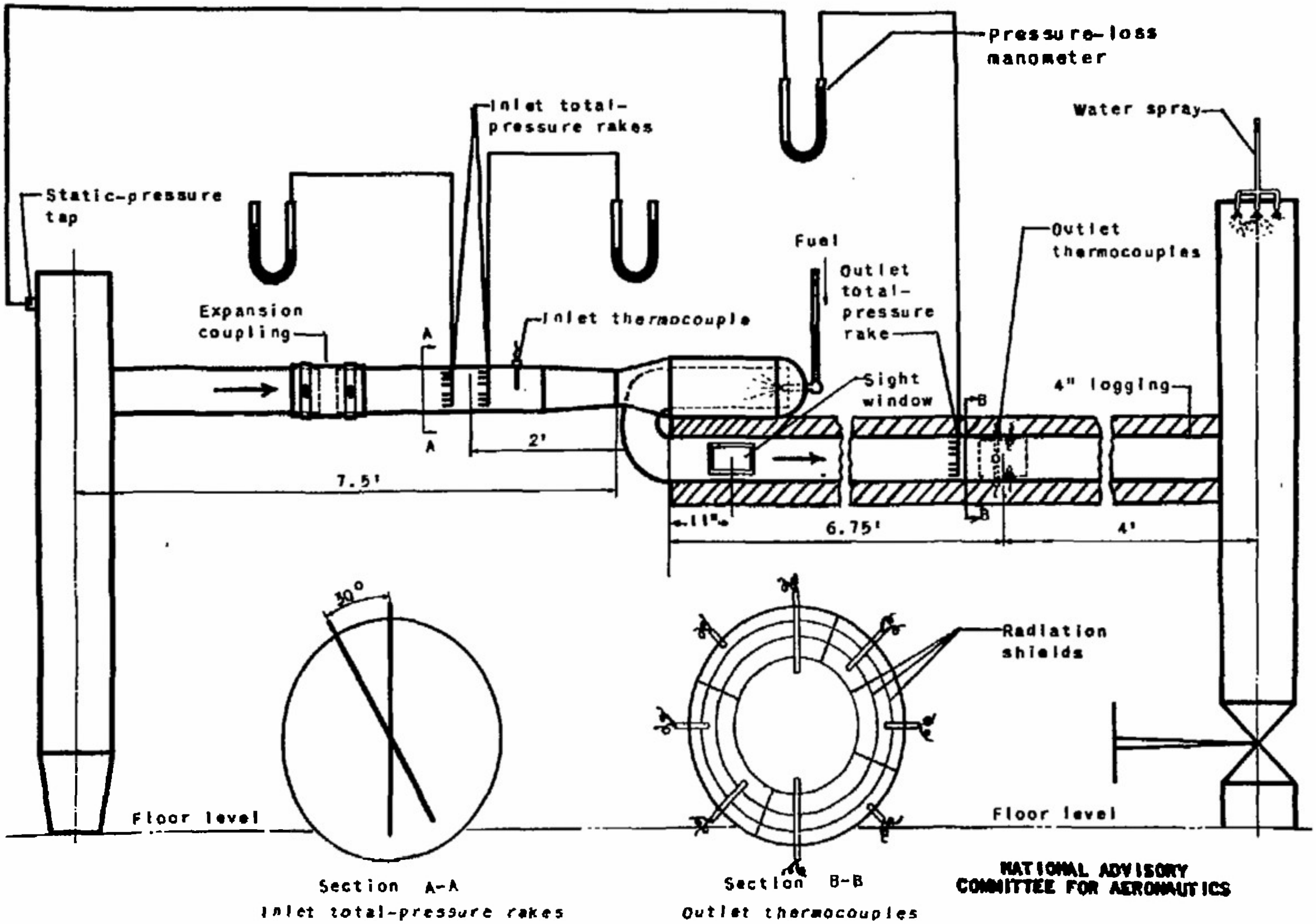

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Figure 3. - Schematic drawing showing the inlet and outlet ducting and the location of pressure tubes and thermocouples in the test section.

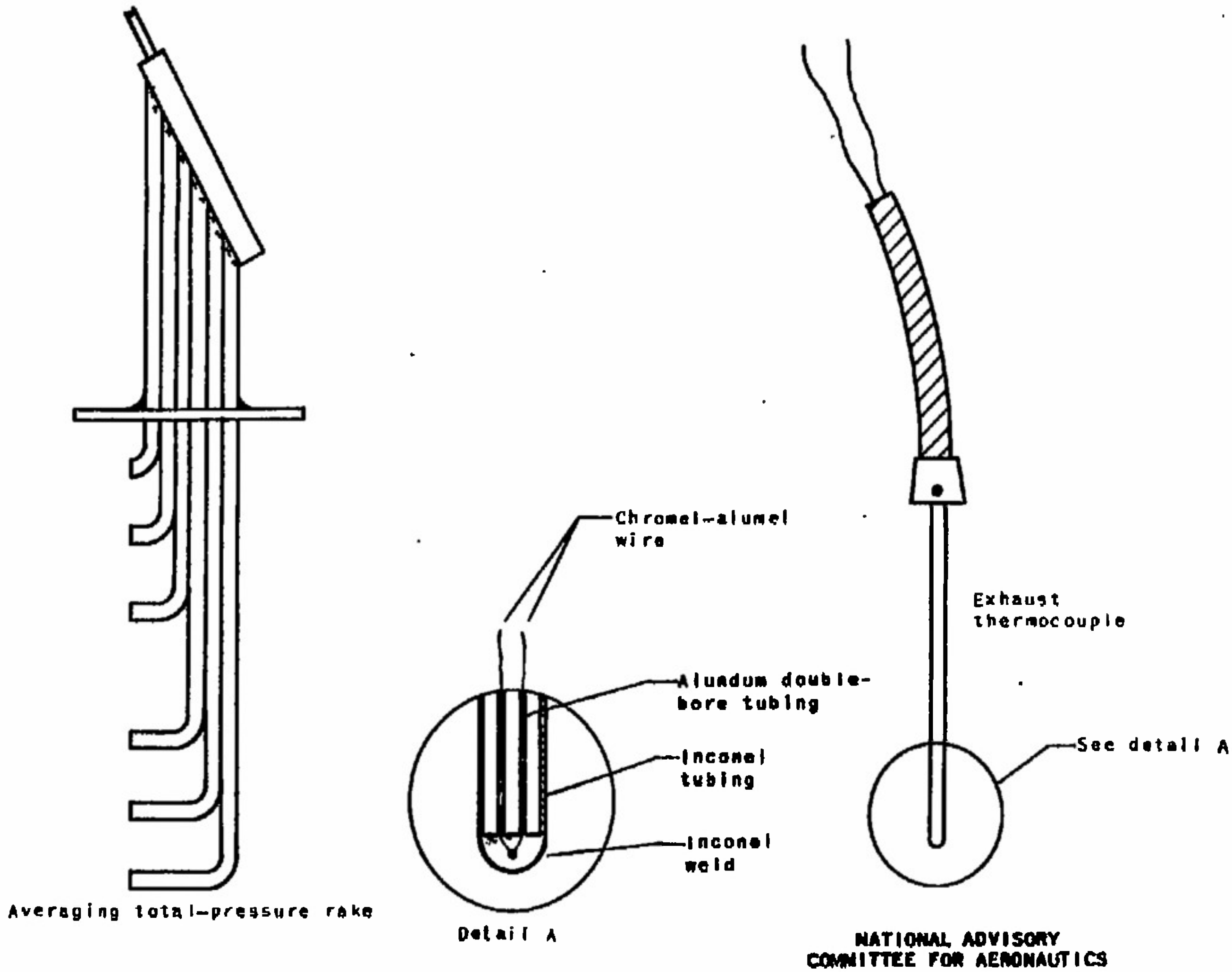

Figure 4. - Design details of total-pressure-survey and temperature-survey instruments.

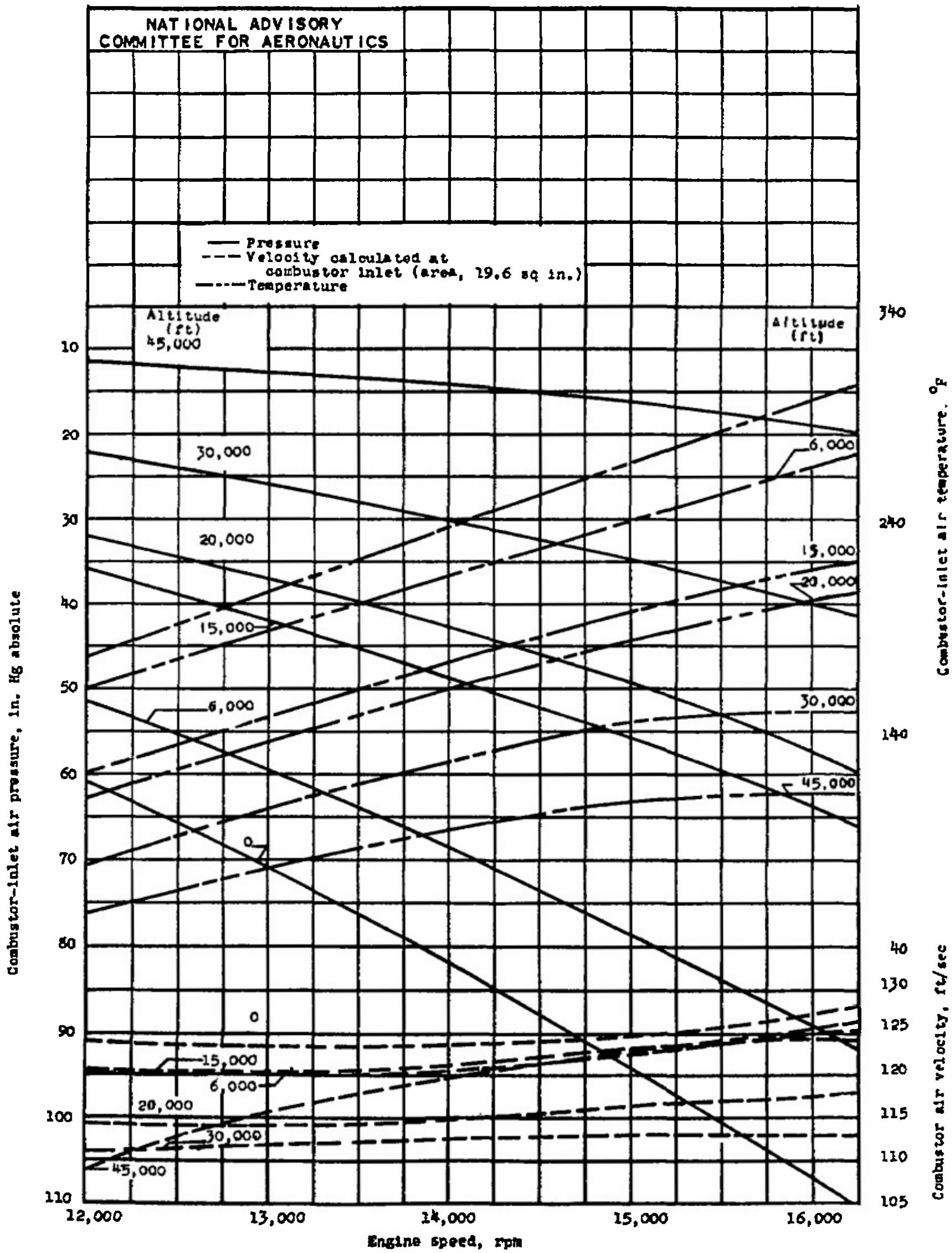

Figure 5. - Control chart for I-16 engine. Zero ram condition.

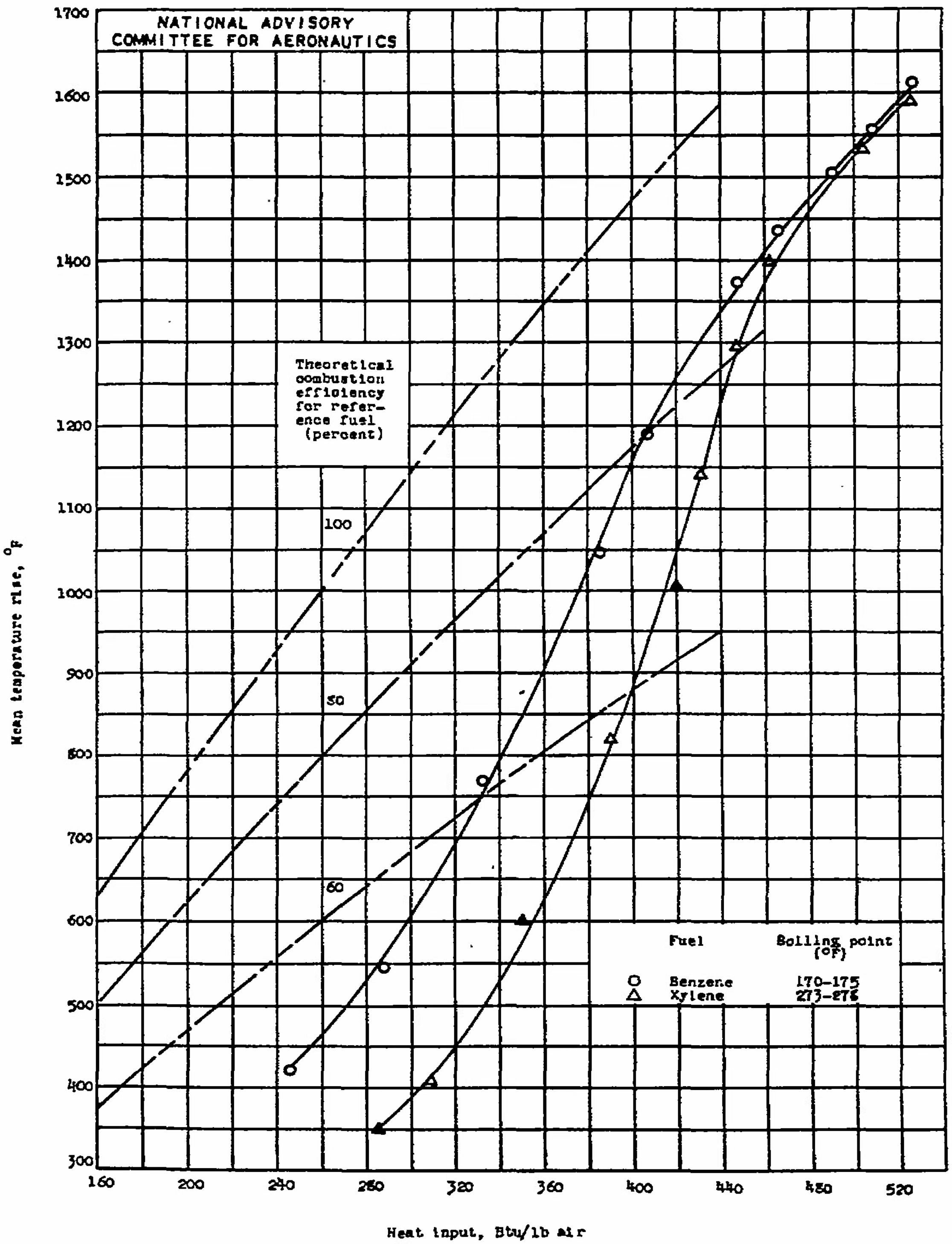

Figure 6. - Variation of mean temperature rise in I-16 combustor with heat input for two commercially pure aromatic hydrocarbons. Simulated altitude, 45,000 feet; simulated rotor speed, 12,200 rpm; inlet-air pressure, 12.3 inches mercury absolute; inlet-air temperature, 75° F; inlet-air velocity, 111 feet per second; reference fuel, solvent 1.

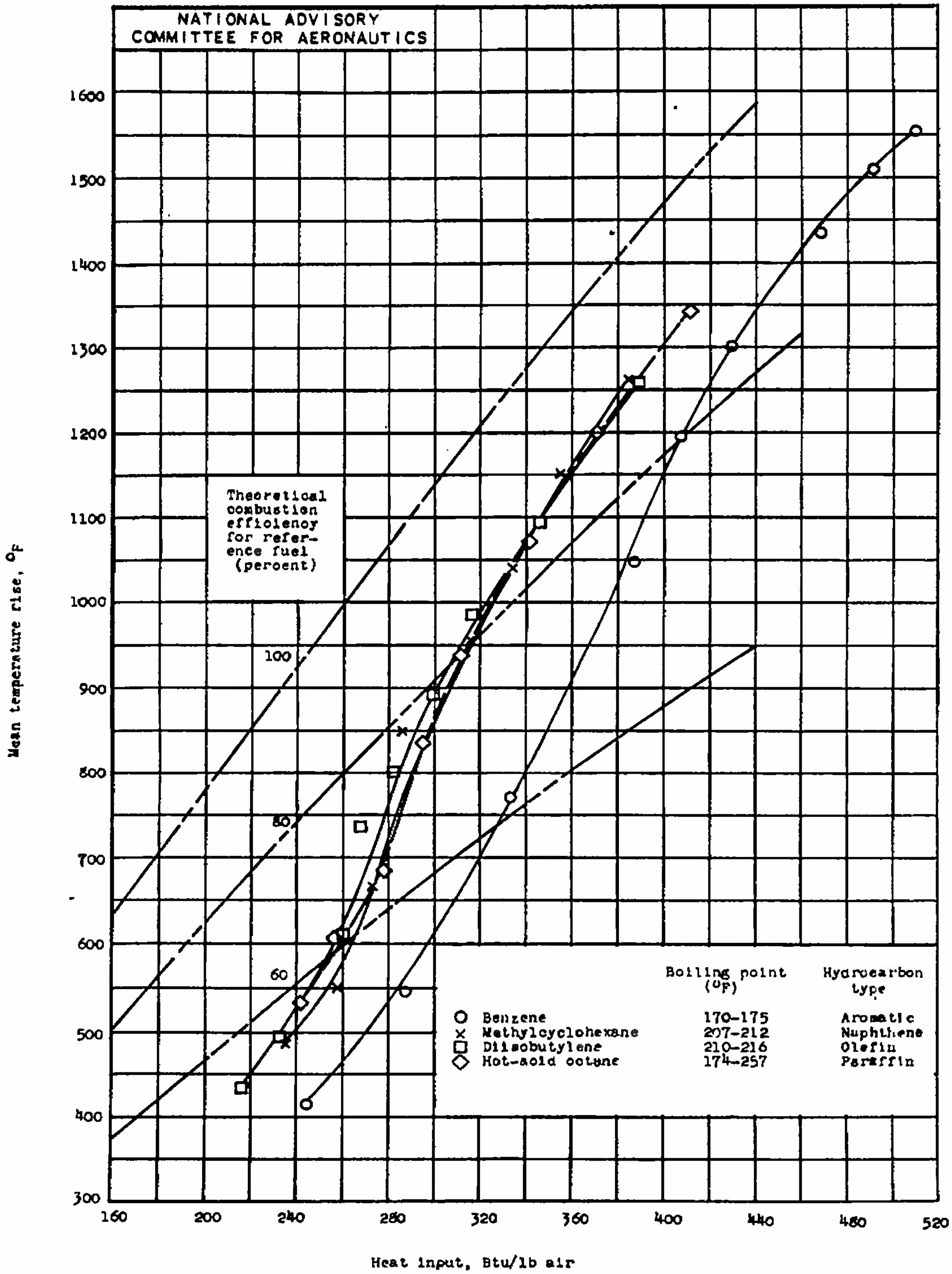

Figure 7. - Variation of mean temperature rise in I-16 combustor with heat input for four commercially pure hydrocarbons. Simulated altitude, 45,000 feet; simulated engine speed, 12,200 rpm; inlet-air pressure, 12.3 inches mercury absolute; inlet-air temperature, 75° F; inlet-air velocity, 111 feet per second; reference fuel, solvent 1.

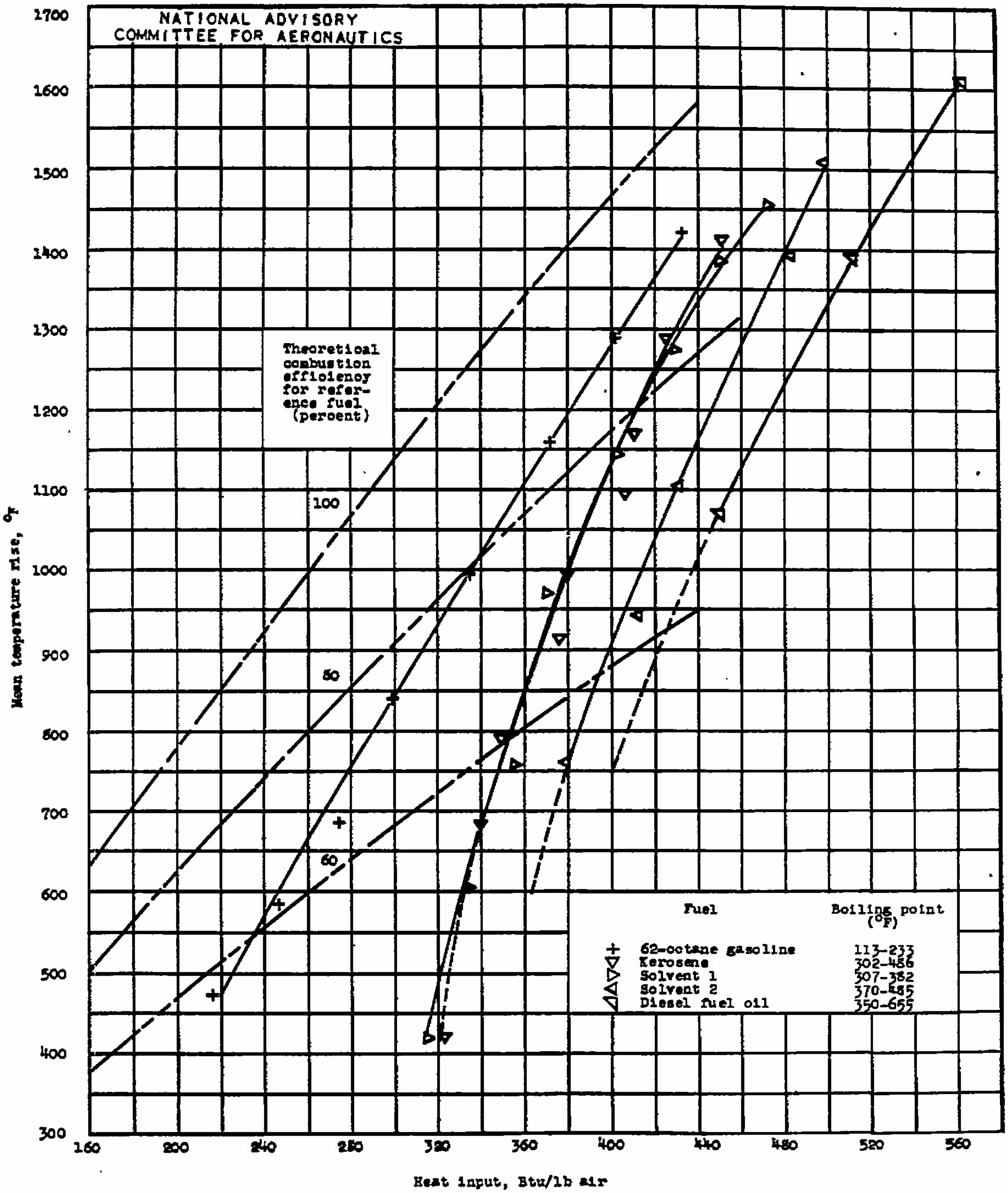

Figure 8. - Variation in mean temperature rise in I-16 combustor with heat input for five hydrocarbon fuel mixtures covering a wide range of boiling points. Simulated altitude, 45,000 feet; simulated rotor speed, 12,200 rpm; inlet-air pressure, 12.3 inches mercury absolute; inlet-air temperature, 75° F; inlet-air velocity, 111 feet per second; reference fuel, solvent 1.

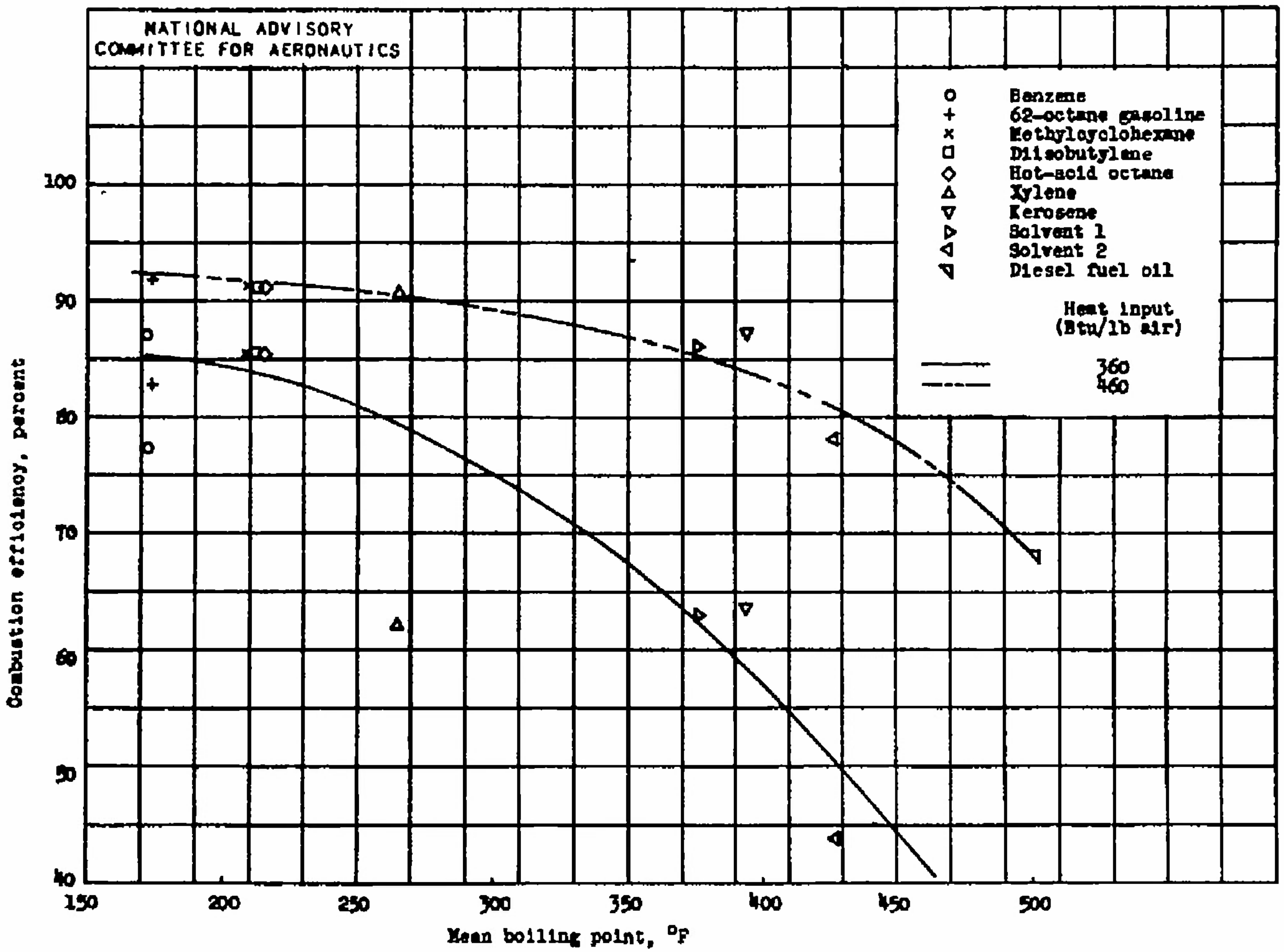

Figure 9. - Variation of combustion efficiency with mean boiling point of fuel at two constant heat inputs. Simulated altitude, 45,000 feet; simulated rotor speed, 12,200 rpm; inlet-air pressure, 12.3 inches mercury absolute; inlet-air temperature, 75° F; inlet-air velocity, 111 feet per second. (Symbols represent positions on faired curves of figures 6, 7, and 8.)

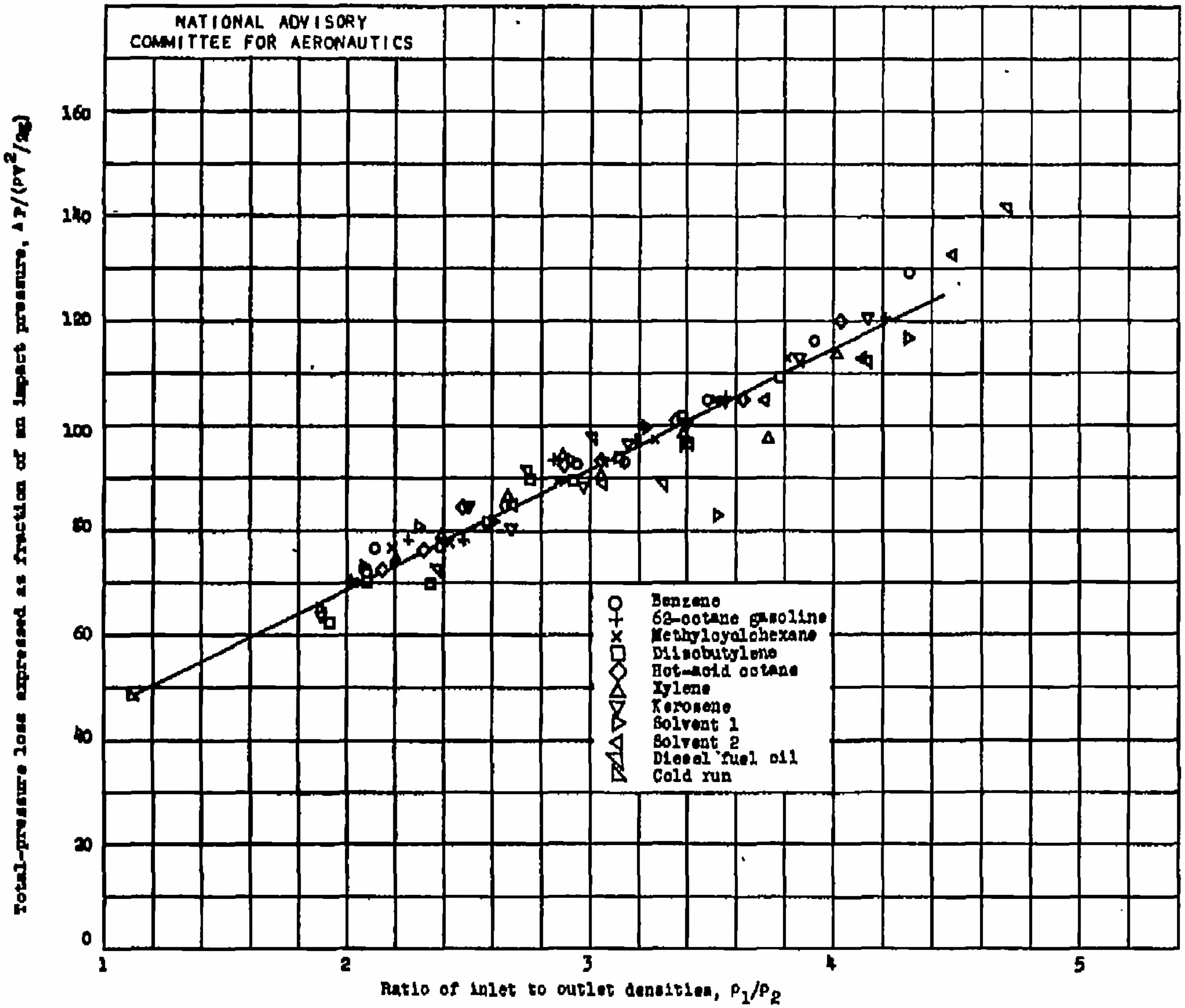

Figure 10. - Total-pressure loss across I-16 test section expressed as a fraction of an impact pressure and as a function of ratio of inlet to outlet densities.

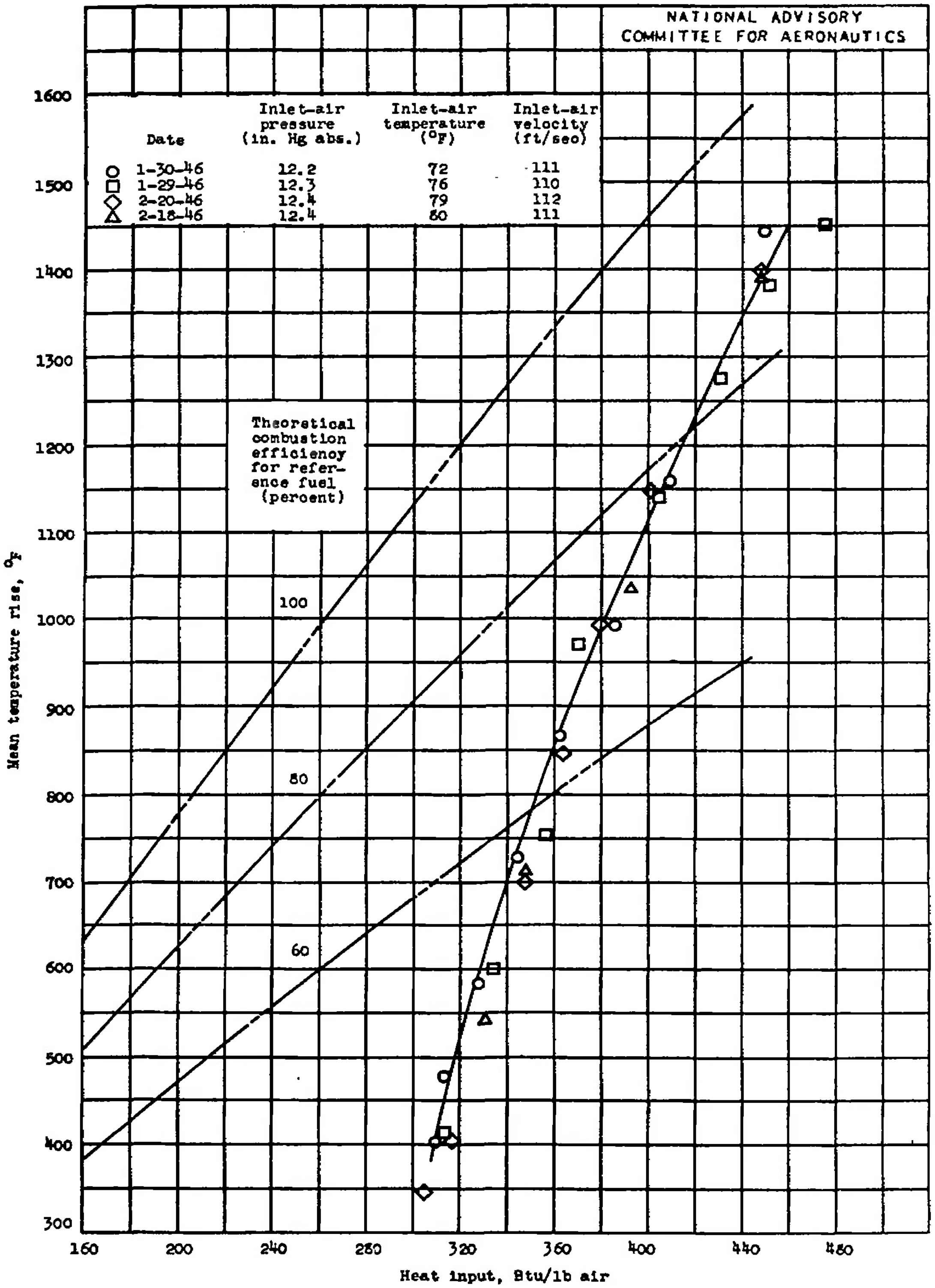

Figure 11. - Differences in combustor performance over period of test program. Fuel, solvent 1; simulated altitude, 45,000 feet; simulated rotor speed, 12,200 rpm.

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ABSTRACT

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