NAEC-AEL-1736

# U.S. NAVAL AIR MATERIAL CENTER

P H I L A D E L P H I A ,   P E N N S Y L V A N I A



AERONAUTICAL ENGINE LABORATORY

NAEC-AEL-1736   15 MAY 1963

## EFFECTS OF JET FUEL CONSTITUENTS ON COMBUSTOR DURABILITY

BY
C.C. McCLELLAND

PHASE C REPORT ON
WEPTASK P.A. NAE-RAPP-41017

NOTICE

Reproduction of this document in any form by other than naval activities is not authorized except by special approval of the Secretary of the Navy or the Chief of Naval Operations as appropriate.

The following Espionage notice can be disregarded unless this document is plainly marked CONFIDENTIAL or SECRET.

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Sections 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

COPY No. 14

RMCD

## TABLE OF CONTENTS


| TITLE | PAGE NO. |
|---|---|
| LIST OF PLATES . . . . . . . . . . . . . . . . . . . . . . . . . | 2-3 |
| INTRODUCTION . . . . . . . . . . . . . . . . . . . . . . . . . | 4 |
| CONCLUSIONS. . . . . . . . . . . . . . . . . . . . . . . . . | 4-5 |
| RECOMMENDATIONS. . . . . . . . . . . . . . . . . . . . . . . | 5 |
| DESCRIPTION. . . . . . . . . . . . . . . . . . . . . . . . . | 5-6 |
| METHOD OF TEST . . . . . . . . . . . . . . . . . . . . . . . . | 6-8 |
| RESULTS AND DISCUSSION . . . . . . . . . . . . . . . . . . . . | 9-13 |
| REFERENCES. . . . . . . . . . . . . . . . . . . . . . . . . | 13 |
| ABSTRACT CARD . . . . . . . . . . . . . . . . . . . . . . . . | |

## LIST OF PLATES


| TITLE | PLATE NO. |
|---|---|
| Variation in Liner Temperature with Combustor Length, 530°F Inlet, 190 BTU/LB AIR | 1 |
| Variation in Liner Temperature with Combustor Length, 530°F Inlet, 240 BTU/LB AIR | 2 |
| Variation in Liner Temperature with Combustor Length, 530°F Inlet, 280 BTU/LB AIR | 3 |
| Variation in Liner Temperature with Combustor Length, 850°F Inlet, 190 BTU/LB AIR | 4 |
| Variation in Liner Temperature with Combustor Length, 850°F Inlet, 240 BTU/LB AIR | 5 |
| Effect of Combustor Fuel Heat Input on Flame Radiation | 6 |
| Luminometer Number vs Liner Temperature, 530°F Inlet Air Temperature | 7 |
| Luminometer Number vs Liner Temperature, 850°F Inlet Air Temperature | 8 |
| Luminometer Number vs Liner Temperature, 190 BTU/LB AIR | 9 |
| Luminometer Number vs Total Flame Radiation, 530°F Inlet Air Temperature | 10 |
| Luminometer Number vs Total Flame Radiation, 850°F Inlet Air Temperature | 11 |
| Luminometer Number vs Total Flame Radiation, 190 BTU/LB AIR | 12 |
| Hydrogen Content vs Liner Temperature, 530°F Inlet Air Temperature | 13 |
| Hydrogen Content vs Liner Temperature, 850°F Inlet Air Temperature | 14 |
| Hydrogen Content vs Liner Temperature, 190 BTU/LB AIR | 15 |

## LIST OF PLATES (CONT)


| | PLATE NO. |
|---|---|
| Hydrogen Content vs Total Flame Radiation, 530°F Inlet Air Temperature | 16 |
| Hydrogen Content vs Total Flame Radiation, 850°F Inlet Air Temperature | 17 |
| Total Flame Radiation vs Liner Temperature, 190 BTU/LB AIR | 18 |
| Effect of Aromatic Structure on Total Radiation | 19 |
| Effect of Aromatic Structure - Liner Temperature vs Aromatic Content | 20 |
| Effect of Aromatic Structure - Liner Temperature vs Hydrogen Content | 21 |
| Effect of Aromatic Structure - Liner Temperature vs Luminometer Number | 22 |
| J79 Combustor Liner Plan View Showing Thermocouple and Radiation Measurement Locations | 23 |
| J79 Single Combustor Test Section | 24 |

## INTRODUCTION

1. Problem Assignment NAE-RAPP-41017, covering the Effects of Jet Fuel Constituents on Combustor Durability, was authorized by Bureau of Naval Weapons letter AER-PP-411/67 of 7 November 1957 and amended by Bureau of Naval Weapons letter RAPP-53/20:TFG of 28 December 1960.

2. The continuous uprating of Navy jet engine performance leads to higher combustion chamber inlet temperatures and higher heat release rates. These conditions place increasingly higher thermal stress on the combustion liner materials. The purposes of this problem assignment are:

a. To measure the effect of flame radiation on liner temperatures.

b. To determine which properties of the fuel influence flame radiation and liner temperatures and whether these properties can be controlled to minimize their effects.

c. To determine the effect of operating variables on flame radiation and liner temperatures.

3. Previous work under this problem assignment has been reported by references a, b, and c. The present phase covers the effects of fuel and combustion variables on liner temperatures and flame radiation of the J79 combustion chamber. The operating conditions have been extended to higher inlet air temperature to show the effect of operation with advanced jet engines. Data from other combustor tests have been included in this report for correlation. The results have been transmitted to the BUWEPS by newsletter and by personal contact.

## CONCLUSIONS

4. Liner temperatures and flame radiation intensity in a J79 combustion chamber are functions of both the luminometer number and the hydrogen content of the fuel. As liner temperature tends to level out above a luminometer number of 100 there is little to be gained from further increase in this parameter.

5. An increase in J79 combustor inlet air temperature will result in increases in flame radiation and in the liner temperature rise above inlet air temperature. The relationships with luminometer number are similar to those at lower temperature.

6. Both luminometer number and hydrogen content of a fuel will provide satisfactory correlations with flame radiation and liner temperatures for future higher combustor inlet temperature conditions.

7. Liner temperatures in a jet engine combustor are directly proportional to the intensity of the total flame radiation received by the liner. The

position and intensity of the flame zone and the maximum liner temperature will vary with differences in combustor design and fuel type at a given set of operating conditions.

8. A fuel containing polycyclic aromatic hydrocarbons will give higher flame radiation intensity and liner temperatures than a fuel containing an equal percentage of monocyclic aromatic hydrocarbons. This fact can be attributed to the differences in hydrogen content of the two aromatic types and is reflected in the differences in luminometer number.

RECOMMENDATIONS

9. In the development of gas turbine engines having higher combustion chamber inlet temperatures than existing engines, correction for the tendency toward higher liner temperatures should be made in improved combustor design and improved materials as the advantage to be gained from higher luminometer number fuels is limited.

10. Limitation of flame radiation and liner temperatures should continue to be accomplished by limiting the luminometer number of the fuel. If a change from this method is contemplated or an alternative is required, the hydrogen content method would be satisfactory.

11. Future work in the study of flame radiation and liner temperatures should include studies of:

a. The relationship between these properties and the presence of carbon in the flames and exhaust gases of jet engine combustors.

b. The effect of combustor design.

c. The effect of higher inlet pressures.

d. Operation with new types of fuels, such as high density, high temperature, or special non-hydrocarbon fuels.

e. The relationship between radiation and liner temperatures at all locations on the combustor.

f. The reasons for failure of some fuels to correlate directly with the established relationships.

DESCRIPTION

12. The J79 combustion system consists of an annular air passage containing ten individual can type combustion chambers. Each combustion chamber has a single duplex type of fuel nozzle. Two combustion chambers are provided with spark plug ignitors. The combustion system used in these tests represents one tenth of the engine combustion system. It contains

one combustion chamber with a fuel nozzle and a spark plug in a housing duplicating that of the engine.

METHOD OF TEST

13. Previous data run in a J57 turbojet engine combustor (reference c) simulated performance conditions in present-day Navy attack bombers flying at maximum range altitude cruise conditions. This report covers a similar set of conditions in a J79-GE-8 turbojet engine combustor. The values of the J79 combustion chamber parameters were:

142 in. of Hga combustor inlet air pressure

530°F combustor inlet air temperature

93 ft per sec combustor reference velocity

7.5 lb/sec combustor air flow

14. Measurements of combustor exit temperature, combustor metal temperature, and total radiation were made with each fuel at three heat input rates of 190, 240 and 280 BTU per pound of air. These heat input rates resulted in average combustor temperature rises of approximately 725, 885, and 1025°F, respectively.

15. In addition, an analysis of the J79-GE-8 combustor flame radiation and liner temperatures was run at conditions simulating high altitude flight with an advanced engine (higher burner inlet temperature.) The test conditions were:

142 in. of Hga combustor inlet air pressure

850°F combustor inlet air temperature

90 ft per sec combustor reference velocity

5.7 lb/sec combustor air flow

190 and 240 BTU/LB AIR heat input rates

These heat input rates resulted in average combustor temperature rises of 690 and 840°F.

16. The high inlet temperature runs (850°F) were achieved by use of a slave burner in the line. A J79 combustion chamber similar to the one under test was used for this purpose. The maximum oxygen consumption was approximately 6.7 percent of that available. The oxygen content of the test combustor air after vitiation was 21.6 percent by weight for these runs. Previous experience with combustion using vitiated air has indicated that this degree of vitiation would have a negligible effect on combustion.

17. The combustor exit temperature was measured by three rakes of three platinum - platinum 13% rhodium thermocouples placed at the turbine position. The combustor metal temperature was measured by 24 chromel-alumel thermocouples welded to its outer surface at six stations along the length.

18. The flame total radiation measurements were made by a Leeds and Northrup Rayotube, modified by sapphire optics, at three positions along the combustor length (20, 40 and 65 percent). Plate 23 shows the positions of thermocouples and radiation ports.

19. The fuels used in this test were selected to cover a wide range of luminometer number rating for comparison with trends in flame radiant energy and combustor metal temperature. Three were wide boiling range fuels and four were single component hydrocarbon fuels. The remaining five were blended by Phillips Petroleum Co. to contain specific quantities of monocyclic and polycyclic aromatic compounds. A list of the fuels with the code numbers used in the test presentation is given in table I. Table II shows the analysis for each of the 12 fuels.

TABLE I

LIST OF FUELS AND NUMBERS USED IN TEST PRESENTATION

1. Normal Heptane
2. "JP-150" Low Luminosity Kerosine
3. Iso-Octane
4. AEL Plant JP-4; MIL-J-5624
5. AEL Plant JP-5; MIL-J-5624
6. Toluene
7. Tetralin
8. Aromatic Free JP-5
9. Number 8 Plus 6.5% Monocyclic Aromatics
10. Number 8 Plus 17.3% Monocyclic Aromatics
11. Number 8 Plus 3.8% Polycyclic Aromatics
12. Number 8 Plus 9.6% Polycyclic Aromatics

20. Plate 24 shows the single J79_GE-8 combustor test section. The outer housing of the test section exactly duplicated a 1/10-sector of the J-79-GE-8 engine compressor discharge, combustion and turbine inlet flow passages.

TABLE II

FUEL ANALYSES

| | Iso-octane | Normal Heptane | JP-150 | AEL Plant JP-4 | AEL Plant JP-5 | Tetralin | Toluene | Fuel No. 8 | Fuel No. 9 | Fuel No. 10 | Fuel No. 11 | Fuel No. 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravity, Specific at 60/60 F | .704 | .6977 | .7197 | .7567 | .8014 | .9718 | .8670 | .7985 | .8038 | .8118 | .8076 | .8212 |
| Gravity, API | | 71.3 | 65.1 | 55.5 | 42.9 | 14.1 | | 45.7 | 44.6 | 42.8 | 43.7 | 40.8 |
| Reid Vapor Pressure, lb/sq. in. | | 1.6 | 1.6 | 2.59 | 0.0 | 0.0 | | 0.80 | 0.00 | 0.80 | 0.25 | 0.75 |
| Distillation, I.B.P. F | | 200 | 206 | 162 | 370 | 388 | 226 | 338 | 362 | 364 | 366 | 366 |
| 5% over, F | 211 | 205 | 222 | 192 | 386 | 392 | 228 | 368 | 376 | 380 | 380 | 380 |
| 10% over, F | | 206 | 228 | 202 | 392 | 392 | 228 | 377 | 380 | 384 | 384 | 386 |
| 20% over, F | | 206 | 234 | 216 | 402 | 394 | 228 | 384 | 385 | 388 | 392 | 394 |
| 30% over, F | | 206 | 242 | 226 | 408 | 394 | 228 | 389 | 391 | 394 | 396 | 400 |
| 40% over, F | | 206 | 248 | 240 | 412 | 394 | 228 | 395 | 396 | 398 | 402 | 404 |
| 50% over, F | | 206 | 259 | 258 | 416 | 394 | 228 | 400 | 402 | 402 | 406 | 408 |
| 60% over, F | | 206 | 268 | 286 | 422 | 394 | 228 | 407 | 407 | 406 | 412 | 414 |
| 70% over, F | | 206 | 280 | 348 | 428 | 394 | 230 | 413 | 412 | 411 | 418 | 420 |
| 80% over, F | | 206 | 296 | 412 | 434 | 396 | 230 | 421 | 420 | 418 | 426 | 428 |
| 90% over, F | | 206 | 318 | 436 | 446 | 396 | 230 | 438 | 435 | 430 | 442 | 442 |
| 95% over, F | | 206 | 340 | 452 | 458 | 400 | 230 | 467 | 462 | 452 | 496 | 466 |
| End Point, F | | 252 | 368 | 476 | 480 | 440 | 276 | 535 | 496 | 490 | 522 | 522 |
| Recovery, % vol. | | | 98.5 | 99.5 | 99.2 | 98.5 | 100.0 | 99.0 | 98.8 | 98.8 | 99.0 | 99.0 |
| Residue, % vol. | | | 0.8 | 0.5 | 0.7 | 0.8 | 0.0 | 0.8 | 1.2 | 1.2 | 1.0 | 1.0 |
| Distillation Loss, % vol. | | | 0.7 | 0.0 | 0.1 | 0.7 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Gum, Accelerated, Mg/100 ml. | | | 0.2 | | | 13.9 | | 2.1 | 3.7 | 4.5 | 2.0 | 1.8 |
| Residue, Air Jet, Mg/100 ml. | | | 0.1 | | | 1.0 | | 2.0 | 2.4 | 1.8 | .6 | .6 |
| Sulfur, % wt. | | 0.016 | 0.02 | | | 0.17 | | .027 | .034 | .028 | .064 | .20 |
| Aromatic Content, % vol. | 0.0 | 0.0 | 3.0 | | | 100 | | 1.46 | 8.06 | 13.90 | 4.25 | 10.0 |
| Aniline Point, C | | 65.4 | 70.6 | | | | | 77.0 | 77.2 | 53.2 | 73.5 | 67.5 |
| Aniline - Gravity Constant | | 10,674 | 10,360 | | | | | 7,779 | 7,741 | 6,240 | 7,189 | 6,271 |
| Heat of Combustion, BTU/lb. | 19,100 | 19,200 | 18,948 | 18,694 | 18,602 | 17,430 | 17400 | 18,756 | 18,700 | 18,596 | 18,695 | 18,899 |
| Corrosion, Copper Strip | | | 1b | | | 1b | | | | | | |
| Freezing Point, F | | | <-90 | -76 | -50 | -70 | | -58°F | -70°F | -70°F | -70°F | -66°F |
| Water Tolerance | pass | pass | pass | | | pass | | | | | | |
| Viscosity at 100°F, cent. | 0.55 | 0.55 | 0.70 | 0.72 | 1.59 | 1.73 | | 8.06 | 7.47 | 6.79 | 6.61 | 7.11 |
| Viscosity at 0°F, cent. | | | | | | | | 1.90 | 1.74 | 1.64 | 1.78 | 1.71 |
| Viscosity at -30°F, cent. | | | | 2.05 | 10.58 | | | | | | | |
| Hydrogen-Carbon Ratio | .189 | .192 | .182 | .158 | .166 | .099 | .0965 | | | | | |
| FIA Analysis %Aromatics | | 0.0 | 2.3 | 12.9 | 14.4 | 99.2 | | | | | | |
| %Olefins | | 0.6 | 2.0 | 1.5 | 2.0 | 0.8 | | | | | | |
| %Saturates | | 99.4 | 95.7 | 85.5 | 83.6 | 0.0 | | | | | | |
| Smoke Point, mm | 40 | >50 | >50 | 25.5 | 23.0 | 7.0 | 10.0 | | | | | |
| Luminometer Number | 100 | 218 | 139 | 71.2 | 45.3 | 0.0 | 6.0 | 68.7 | 55.8 | 42.7 | 52.7 | 38.6 |
| Hydrogen Content, % | 15.9 | 16.1 | 15.4 | 14.2 | 13.6 | 9.0 | 8.8 | 14.4* | 14.2* | 13.9* | 14.0* | 13.5* |

*From reference (4)

RESULTS AND DISCUSSION

21. Plates 1 through 5 show the variation of liner temperature with distance from the front of the liner for all fuels and conditions. Each point represents the average of four thermocouples at that station. The highest average station temperature was at the 30% zone in all cases. There is a tendency, however, for downstream points to become higher as heat input (BTU/LB AIR) increases, indicating a possible shift in the flame position.

22. Table 3 shows the radiation values for the same conditions. For the 850°F inlet air temperature points, the only radiation data are at the 40% zone, because carbon from the slave burner obscured the sapphire windows at the other stations. Comparisons of radiation data between the two inlet temperature conditions will therefore be made only at the 40% zone. The 530°F inlet air temperature data show a rising trend in radiation toward the rear of the combustor and a maximum value at the 65% zone. These data also show a shift of the flame downstream at higher heat input. Plate 6 illustrates these effects with two fuels. The radiation maximum does not correspond with that of temperature. This apparent anomaly is probably due to more efficient wall cooling at the zone where radiation is highest.

23. Reference c showed that the highest liner temperature of the J57 combustor falls at the extreme upstream end (zero percent zone). The radiation data also indicated a rising trend toward the upstream end of the combustor. These differences between the two combustors are due to differences in combustor design. They indicate that the flame is farther downstream in the J79 for the conditions tested.

24. Plates 7 and 8 are plots of fuel luminometer number versus average liner temperature and maximum liner temperature. The curves are similar to those reported in references a through c. Temperature varies considerably with luminometer number at low numbers but approaches a limiting value at high luminometer numbers. Data from conditions which duplicate those run in previous tests do not necessarily repeat the same values because of small differences in thermocouple locations, as well as the relatively large effect of small variations in fuel nozzle and combustor liner installation and combustor surface condition. These curves show a slight decrease in both maximum and average liner temperatures at the higher heat input rate for the 530°F condition. This decrease is probably due to the downstream shift of the flame front previously mentioned. The more efficient cooling downstream causes the overall average temperature to drop slightly.

25. Luminometer number versus the increase in average liner temperature above inlet air temperature (liner temperature rise) has been plotted for both inlet air temperatures on plate 9. There is a significant increase in liner temperature rise when the inlet air temperature is increased. This fact is probably due to the existence of a hotter, more compact flame in the relatively little cooled primary zone due to faster fuel vaporization and increased reaction rate at the higher

TABLE III

| Fuel Number | BTU/LB AIR | Transverse Flame Radiation, BTU/SQ FT/HR x $10^3$ 530°F Inlet Air Temperature 26% | 40% | 65% | 850°F I.A.T. 40% |
|---|---|---|---|---|---|
| 1 | 190 | 55 | 58 | 59 | 75 |
| 1 | 240 | 41 | 51 | 69 | 65 |
| 1 | 280 | 32 | 43 | 64 | -- |
| 2 | 190 | 65 | 74 | 80 | 94 |
| 2 | 240 | 55 | 69 | 85 | 88 |
| 2 | 280 | 43 | 54 | 83 | -- |
| 3 | 190 | 71 | 74 | 80 | 90 |
| 3 | 240 | 57 | 65 | 77 | 55 |
| 3 | 280 | 40 | 49 | 80 | -- |
| 4 | 190 | 78 | 117 | 123 | 140 |
| 4 | 240 | 71 | 112 | 133 | 135 |
| 4 | 280 | 60 | 94 | 138 | --- |
| 5 | 190 | 93 | 149 | 159 | 142 |
| 5 | 240 | 80 | 139 | 178 | 130 |
| 5 | 280 | 68 | 116 | 178 | --- |
| 6 | 190 | 31 | 280 | 328 | 277 |
| 6 | 240 | 34 | 265 | 374 | 280 |
| 6 | 280 | 30 | 227 | 390 | --- |
| 7 | 190 | 239 | 280 | 335 | 287 |
| 7 | 240 | 159 | 265 | 377 | 277 |
| 7 | 280 | 68 | 222 | >265 | --- |
| 8 | 190 | 75 | 95 | 110 | 110 |
| 8 | 240 | 71 | 98 | 115 | 98 |
| 8 | 280 | 54 | 74 | 117 | --- |
| 9 | 190 | 80 | 130 | 126 | 138 |
| 9 | 240 | 76 | 121 | 131 | 131 |
| 9 | 280 | 72 | 115 | 133 | --- |
| 10 | 190 | 83 | 140 | 151 | 152 |
| 10 | 240 | 79 | 119 | 167 | 169 |
| 10 | 280 | 58 | 103 | 155 | --- |
| 11 | 190 | 75 | 121 | 141 | 131 |
| 11 | 240 | 74 | 109 | 147 | 120 |
| 11 | 280 | 64 | 92 | 140 | --- |
| 12 | 190 | 83 | 132 | 167 | 147 |
| 12 | 240 | 76 | 126 | 175 | 147 |
| 12 | 280 | 67 | 117 | 179 | --- |

temperature. It would be important in design of combustors operating at high inlet air temperatures to consider that the increase in liner temperatures will be higher than the increase in inlet air temperatures.

26. Plates 10 and 11 show the relationship between fuel luminometer number and flame radiation at the 40% zone. Again, the curves are similar to those previously obtained. As shown on plate 12, the inlet air temperature does not significantly affect the shape of the curve but an increase in radiation is seen for the higher inlet air temperature. This effect supports the relative increase in liner temperature discussed previously. There is also an increase in flame radiation with decrease in energy input. This effect may be due to the downstream shift of the flame.

27. The hydrogen content of fuel has been used as an indicator of relative liner temperature and is discussed in reference g. Plates 13 and 14 show this relationship for the present tests. A straight-line relationship exists for both average and maximum liner temperature. A comparison of these curves with plates 5 and 6 shows no significant difference in the degree of data scatter between the two methods of plotting. A large part of the scatter is undoubtedly due to inherent inaccuracies in the burner test. This factor would be common to both correlations. Some of the points show a consistent variation from the curves, however, suggesting that neither method of correlation incorporates all the fuel properties which influence radiation and liner temperature.

28. Plate 15 shows the increase in liner temperature rise at higher inlet air temperature. This effect apparently decreases with fuels of lower hydrogen content.

29. Plates 16 and 17 are plots of hydrogen content versus flame radiation. The correlation is good and scatter appears to be less than in the plots of luminometer number versus radiation (plates 10 and 11). As in plates 10 and 11, a decrease in radiation at the 40% zone with increasing energy input can be seen for both inlet air temperatures.

30. A comparison of several combustion systems with respect to the correlation between flame radiation and liner temperatures is shown on plate 18. The liner temperature used is the average at the 30% zone. For the J79 combustor this is the highest station temperature and it shows the most sensitivity to radiation. J79 radiation was measured at 40% of the burner length, the others at approximately 30%. There is a striking similarity in the curves, indicating an essentially linear relationship between flame radiation and liner temperatures for all combustors. The curves cannot be compared as to absolute values of radiation and temperature because the peak values for the various combustors fall at different zones along the combustors. A plot of data taken at another zone might show a different relationship between burners than that shown here.

31. There is, however, a variation in metal temperatures at a given flame radiation value for the three combustors. This is attributed to differences in the design of the combustors. The J57 combustor which is cooler, has no physical air division between the primary (combustion) and secondary (dilution) air supplies. This design allows all the available air to pass over the surface of the primary zone of the liner. The J79 combustor is a cannular type with a shroud dividing the primary and secondary air passages. There is, therefore, less air flowing over the primary liner surface, hence less cooling effect. The Phillips combustor, which has the highest liner temperatures, has no provision for wall cooling. In addition, this liner has 1/8-in. thick walls which increase the cooling problem.

32. The slight curvature of the J57 line on plate 18 may be due to a greater tolerance of the J57 to radiant heating as suggested in reference e. The difference in temperature between the two J79 curves is greater than the difference in inlet air temperatures. This effect indicates that the rise in liner temperature above that due to the rise in inlet air temperature may be partly due to other factors than radiation, such as convective heat transfer from a hotter flame.

33. Some of the fuels used in this test were blended by the Phillips Petroleum Co. to contain known percentages of specific aromatic hydrocarbons (table I). It was intended to determine the relative effect of monocyclic and polycyclic hydrocarbons on flame radiation and liner temperatures. Earlier tests at AEL showed this effect when the fuels were burned in the J57 combustor. Reference d showed that the monocyclic aromatics gave a lower flame radiation for a given aromatic content than did the polycyclic aromatics.

34. As shown on plate 19, this effect did not appear at the 40% zone of the J79 combustor. Further downstream however, at 65% burner length, the 530°F inlet air temperature data again show a lower radiation level for the monocyclic aromatics.

35. Plate 20 shows this effect for liner temperatures at the peak 30% zone. The relative severity of polycyclic hydrocarbons may be explained by the fact that liner temperatures and radiation are inversely proportional to the hydrogen content of the fuel. Since monocyclic aromatics have a higher percentage of hydrogen than polycyclics do, they should give lower liner temperatures. The same liner temperatures are plotted on plate 21 against hydrogen content of the fuel. Here the differences between the two types of aromatics have been canceled out and a slight reversal has occurred. On plate 22, where the luminometer number is used as a basis for comparison, the two curves coincide. It is difficult to generalize on this subject because the relationships vary depending on the zone selected for comparison. On the basis of the data shown, however, it is suggested that the use of luminometer number or hydrogen content to control fuel combustion cleanliness will accommodate for the effects of aromatic structure on liner maximum temperatures.

36. Combustion efficiencies were calculated for all the runs in the test program. Efficiencies were found to vary between 95% and 100%. There was no significant trend with any of the variables studied.

REFERENCES

37. Reference material noted in this report is as follows:

a. Naval Air Material Center letter XE-3:TAB:jmc NA02/2 of 11 May 1961.

b. Naval Air Material Center letter XE-3:TAB:mlm NA02/2 of 29 September 1960.

c. Naval Air Material Center letter XE-3:jmc NA02/2 of 5 June 1959.

d. Kittredge, G.D.; "Gas Turbine and Jet Engine Fuels", Progress Report No. 1, Navy Contract NOas 60-6009-C Phillips Research Division Report 2508-59R, December 1959.

e. Schirmer, R.M.; "Gas Turbine and Jet Engine Fuels", Progress Report No. 4, Navy BUWEPS Contract NO (w) 61-0590-d, Phillips Research Division Report 2977-61R September 1961.

f. Streets, W.L.; "Gas Turbine and Jet Engine Fuels", Summary Report, Navy BUWEPS Contract No. (w) 61-0590-D, Phillips Research Division Report 3185-62R, March 1962.

g. Schirmer, R.M.; "Jet Fuel Hydrogen Content for Control of Combustion Cleanliness", Navy BUWEPS Contract N600 (19)-58219, Phillips Research Report 3195-62R, June 1962.

Prepared by:

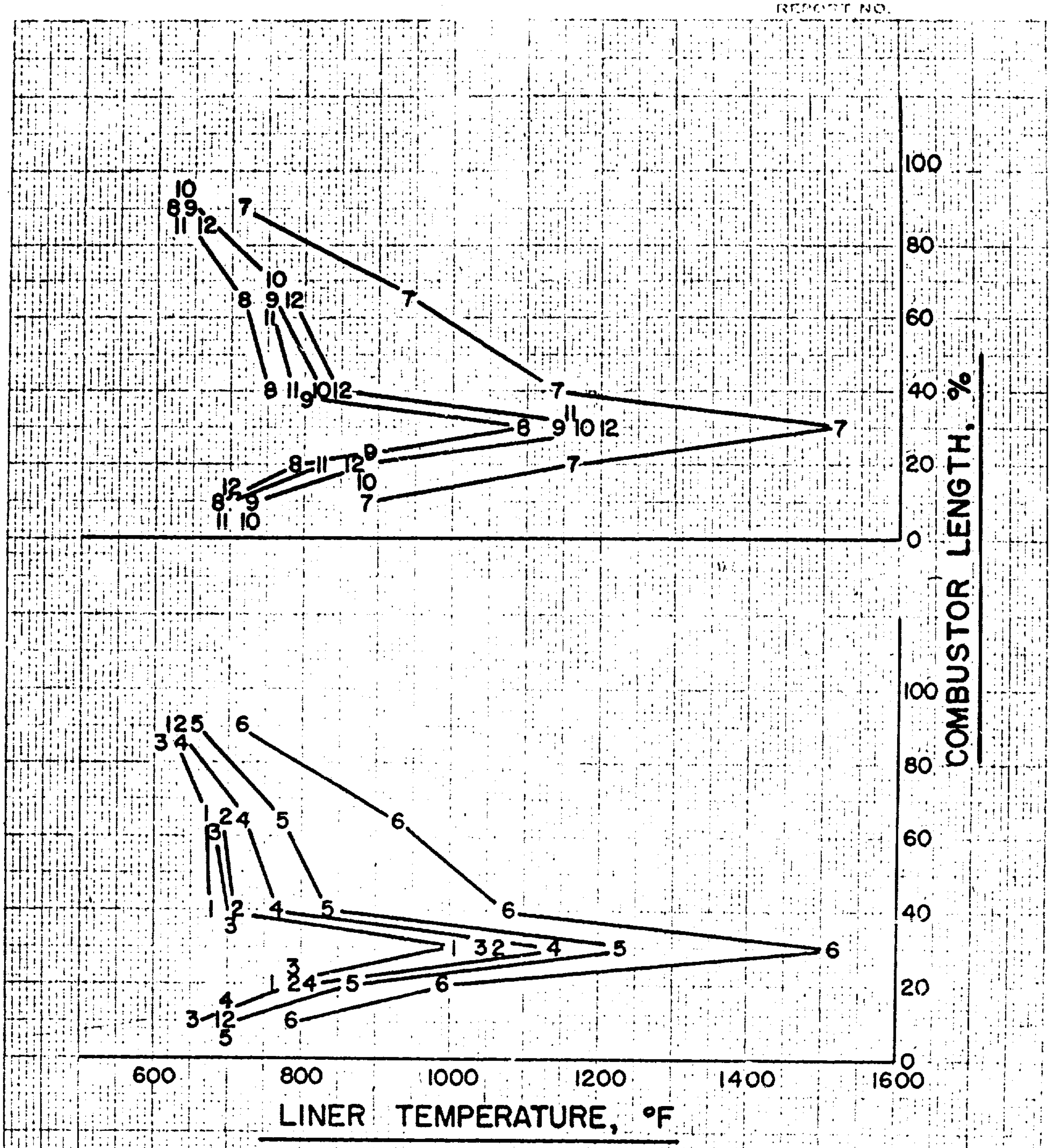
C.C. McClelland
C.C. McClelland
P.A. Engineer

Approved by:

L. Maggitti
L. Maggitti
Fuels and Combustion Branch

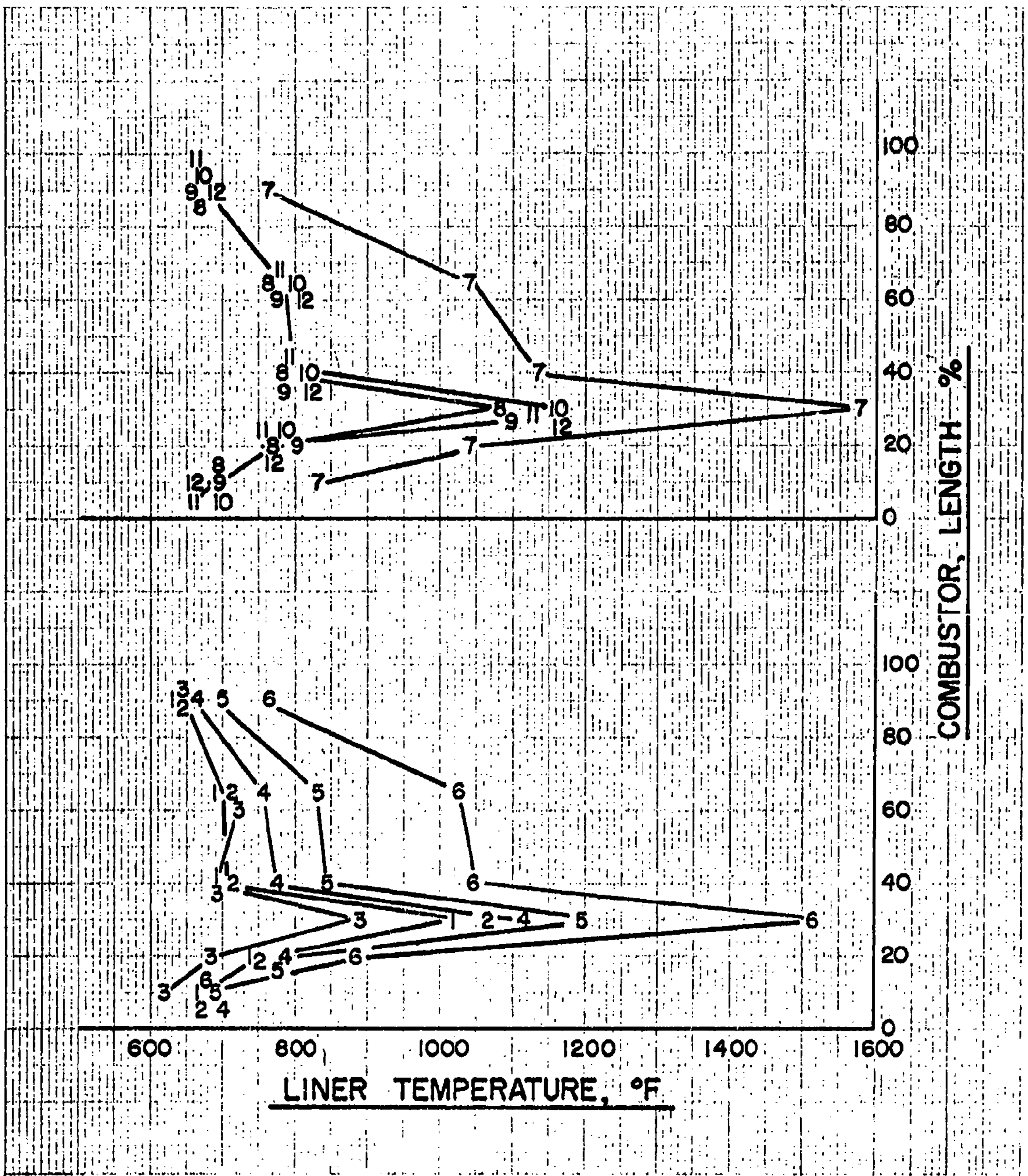
G.H. McCormick
G.H. McCormick, Commander, USN
Acting Director, Aero. Eng. Lab.

REPORT NO.




VARIATION IN LINER TEMP. WITH COMBUSTOR LENGTH
530°F INLET, 190 BTU/LB. AIR

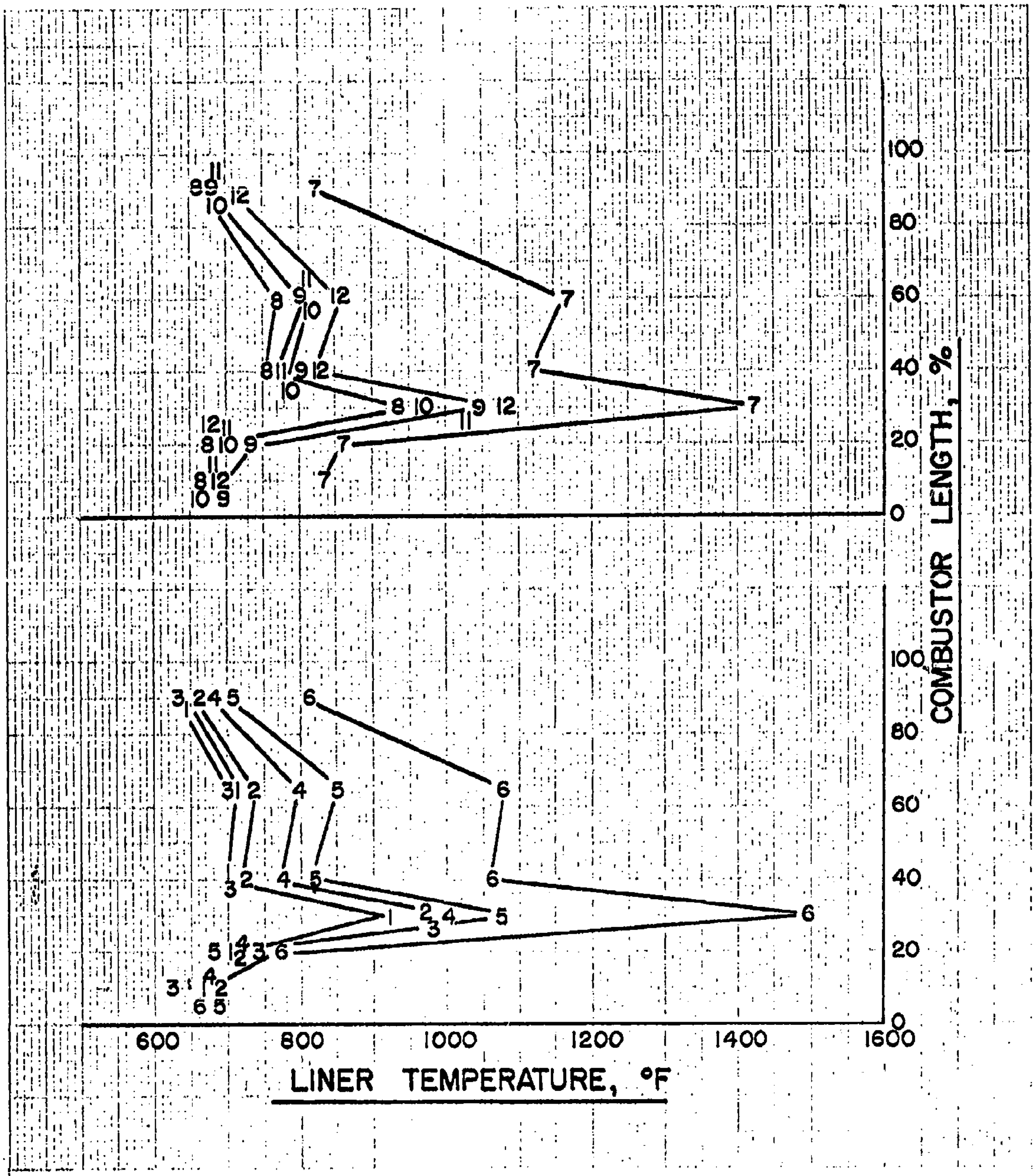
RAPP 41017 Mc CLELLAND




VARIATION IN LINER TEMP.
WITH
COMBUSTOR LENGTH
530°F INLET, 240 BTU/LB. AIR

RAPP 41017 Mc CLELLAND

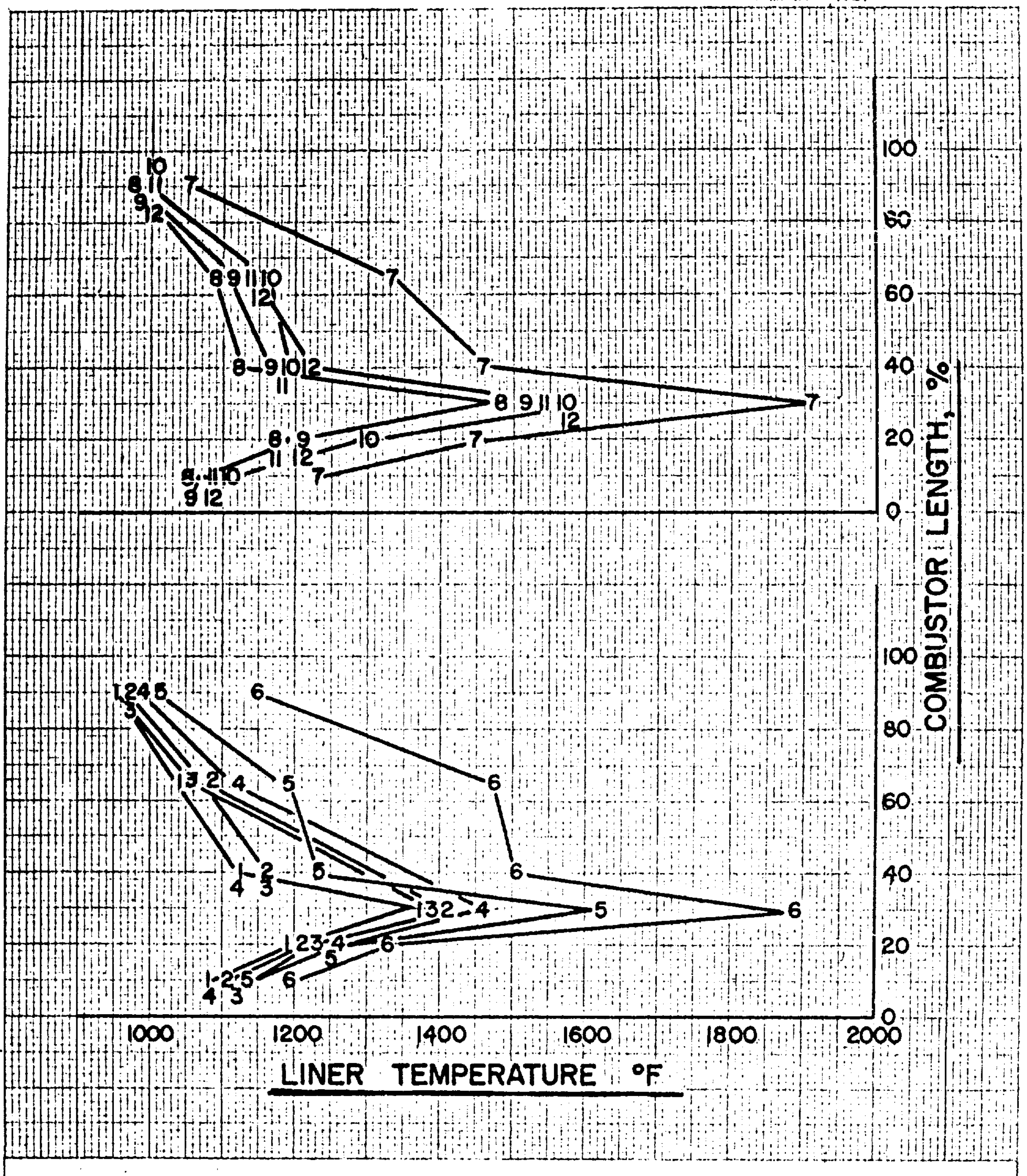
REPORT NO.




VARIATION IN LINER TEMP.
WITH
COMBUSTOR LENGTH
530°F INLET, 280 B.T.U./LB. AIR

RAPP 41017 Mc CLELLAND

REPORT NO.



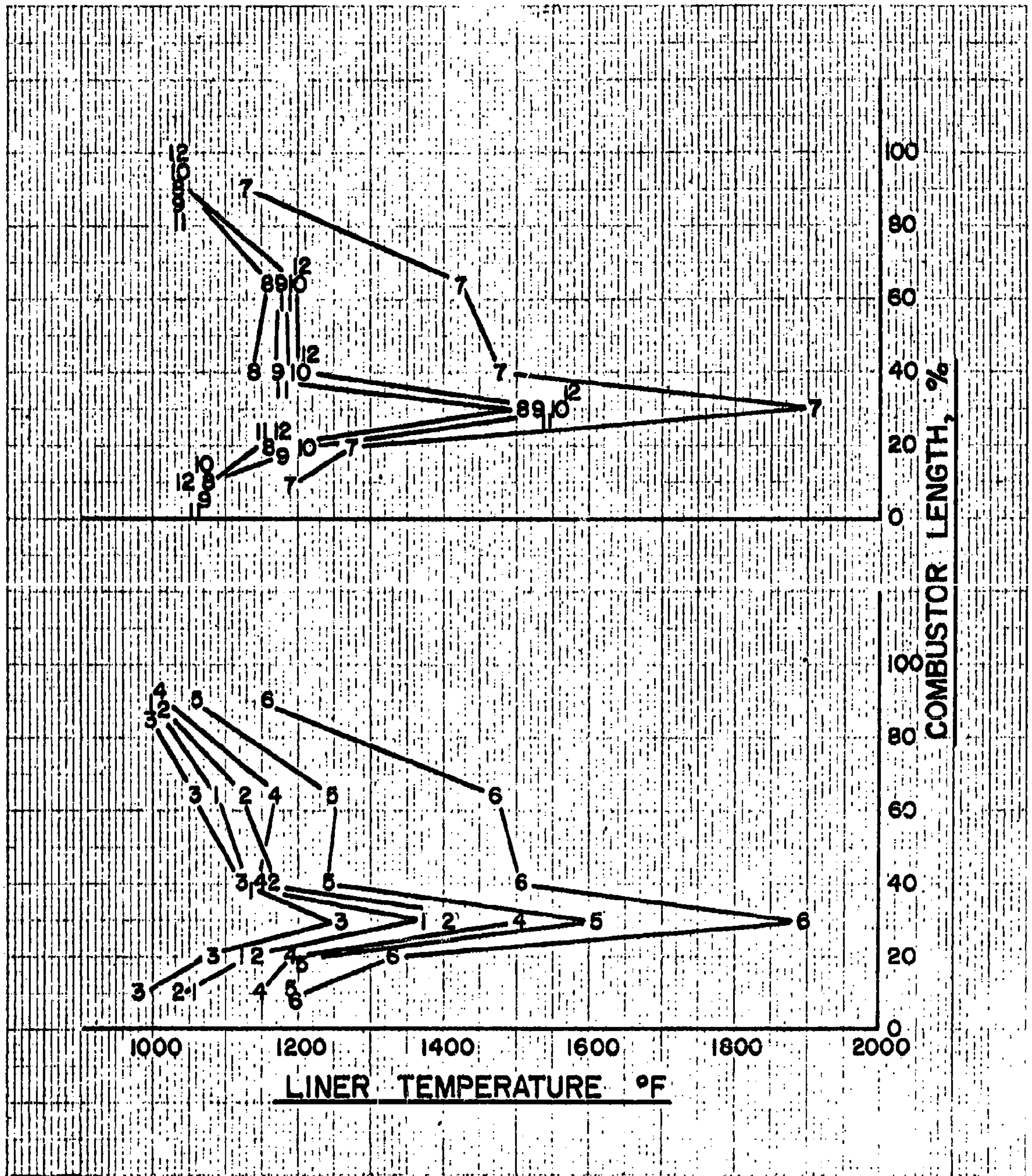

VARIATIONS IN LINER TEMP. WITH COMBUSTOR LENGTH
850 °F INLET, 190 BTU/LB. AIR

AERONAUTICAL ENGINE LABORATORY

P. A. NAM RAPP 41017 ENG'R Mc CLELLAND

PLATE 4

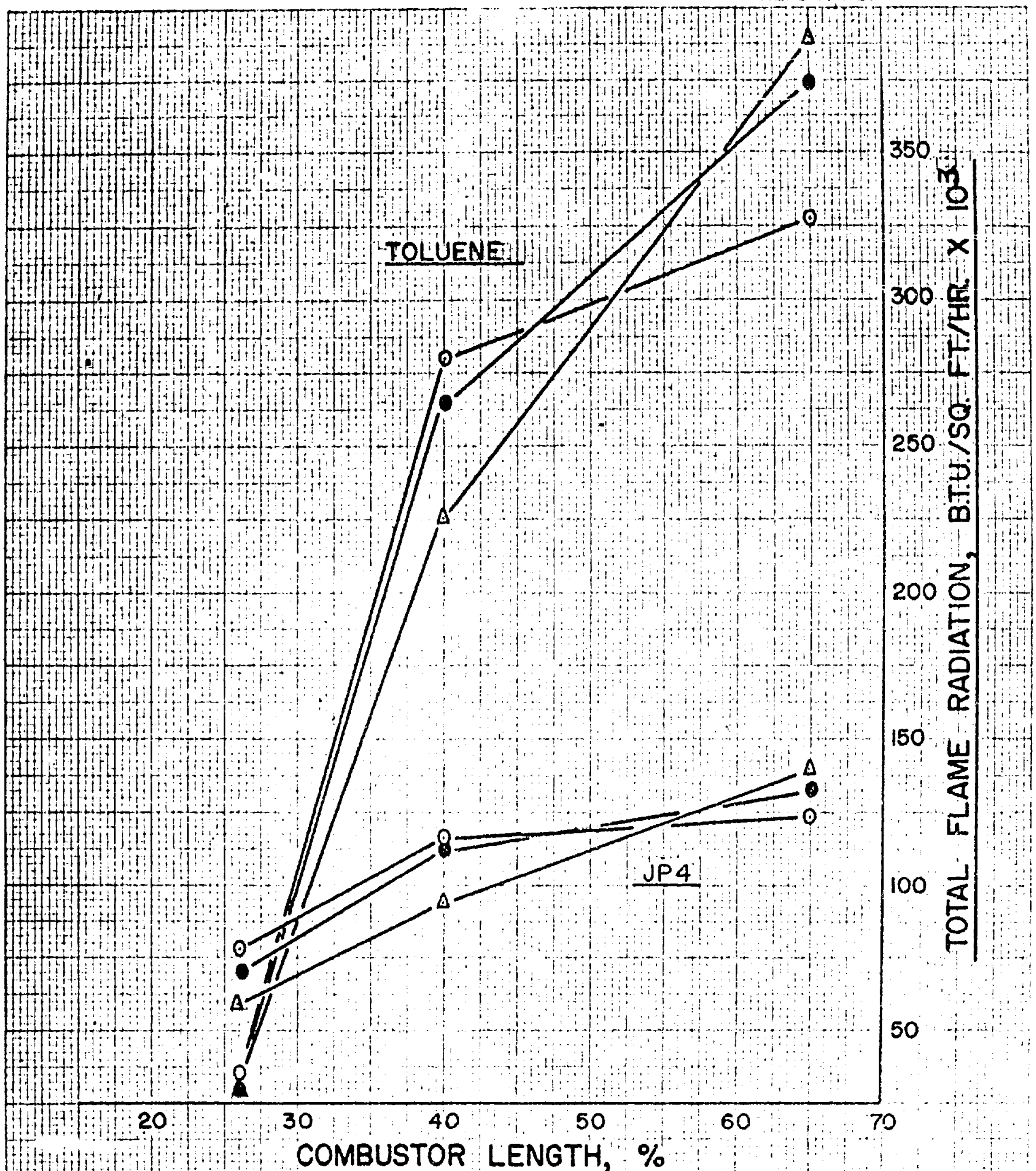
REPORT NO.




VARIATION IN LINER TEMP.
WITH
COMBUSTOR LENGTH
850 °F INLET, 240 BTU/LB. AIR

RAPP 41017 Mc CLELLAND

REPORT NO.




| ***SYMBOL*** | ***HEAT INPUT*** |
| --- | --- |
| ⊙ | 190 B.T.U./LB. AIR |
| ● | 240 B.T.U./LB. AIR |
| Δ | 280 B.T.U./LB. AIR |

INLET AIR TEMP. = 530°F

EFFECT OF COMBUSTOR FUEL HEAT INPUT ON FLAME RADIATION

RAPP 41017 Mc CLELLAND

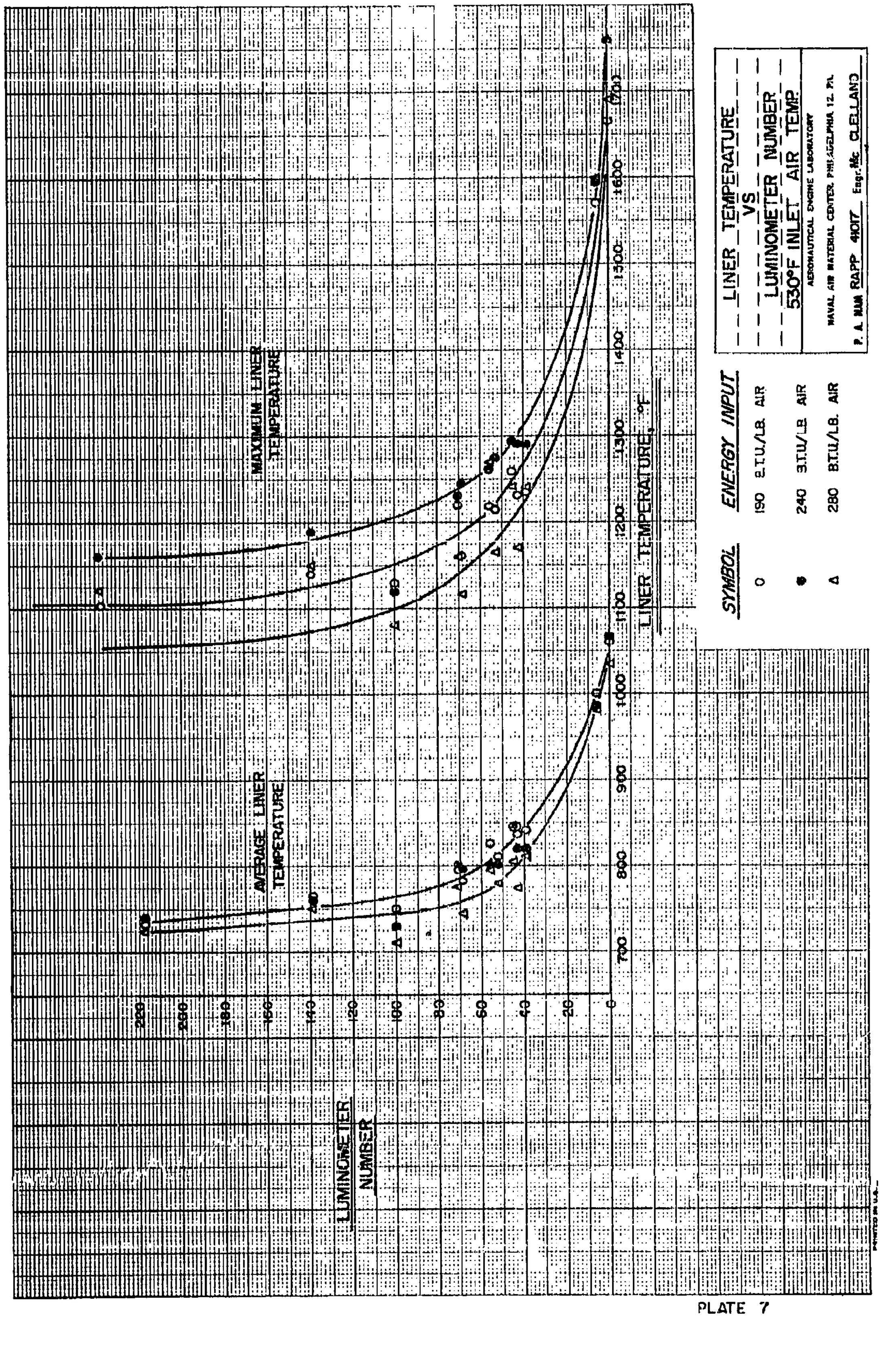
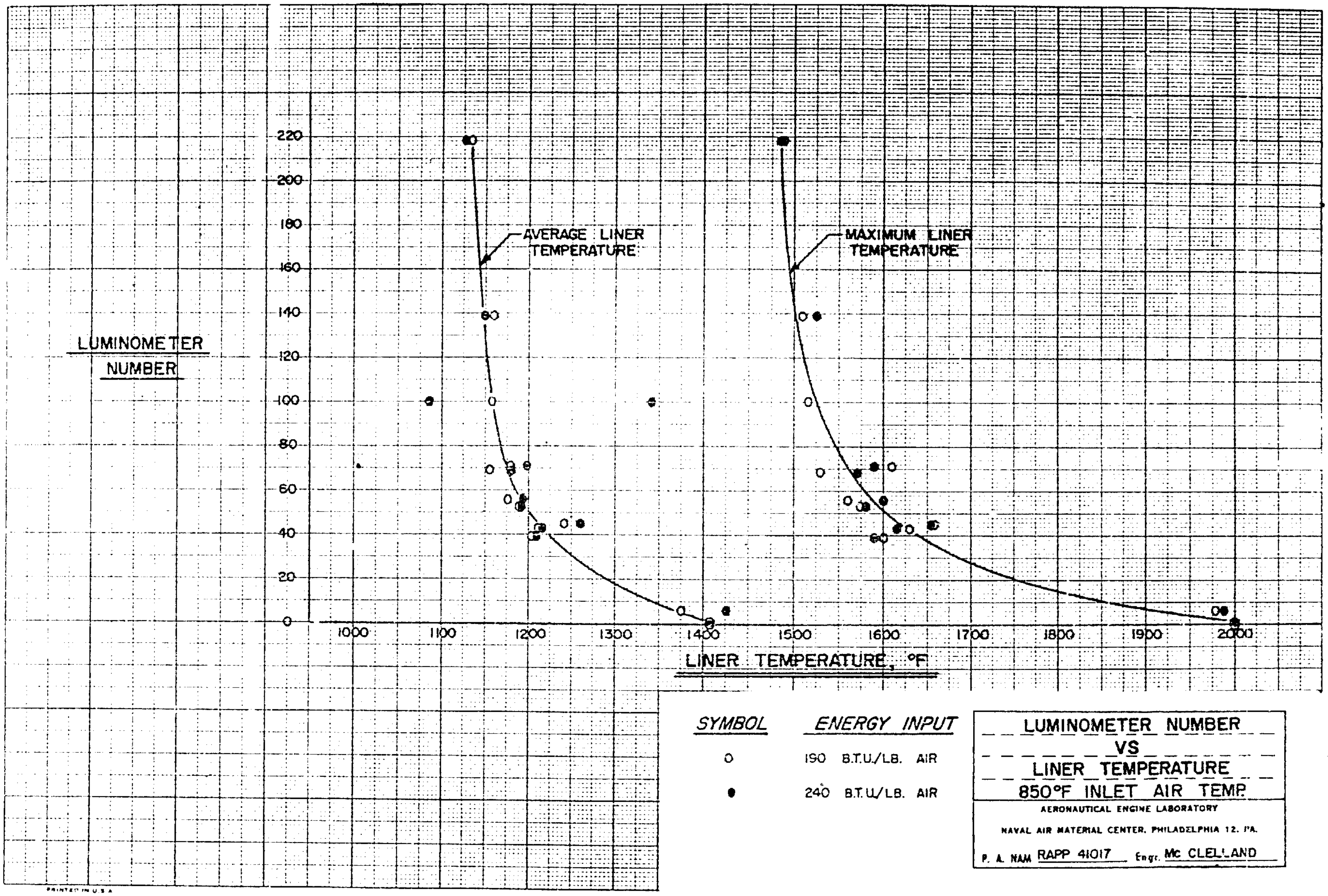

LUMINOMETER NUMBER
LINER TEMPERATURE, °F
AVERAGE LINER TEMPERATURE
MAXIMUM LINER TEMPERATURE
0
20
40
60
80
100
120
140
160
180
200
220
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
SYMBOL
ENERGY INPUT
190 B.T.U./LB. AIR
240 B.T.U./LB AIR
280 B.T.U./LB. AIR
LINER TEMPERATURE
VS
LUMINOMETER NUMBER
530°F INLET AIR TEMP
AERONAUTICAL ENGINE LABORATORY
NAVAL AIR MATERIAL CENTER, PHILADELPHIA 12, PA.
Engr. Mc CLELLAND

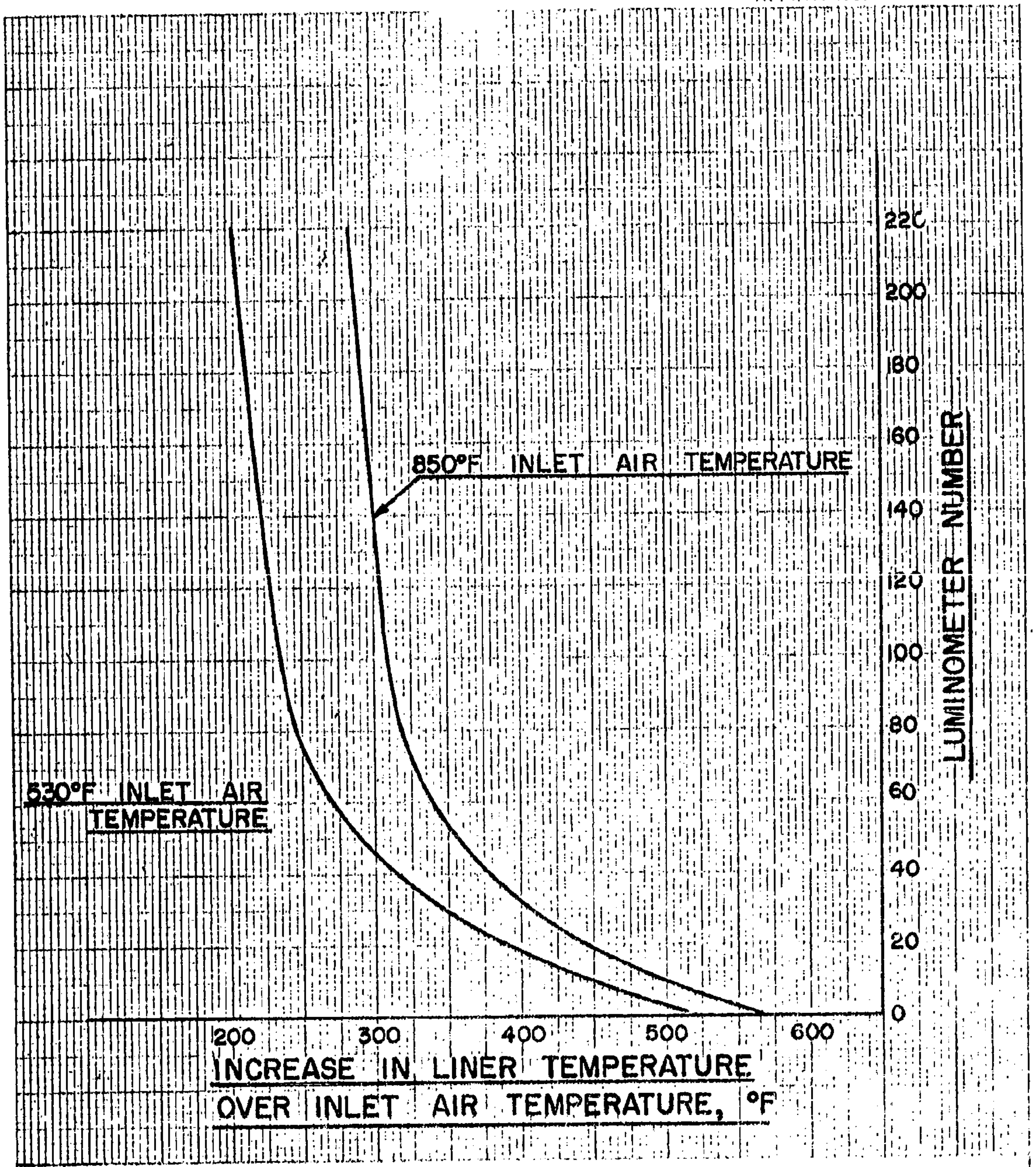
PLATE 7



LUMINOMETER NUMBER
220
200
180
160
140
120
100
80
60
40
20
0
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
LINER TEMPERATURE, °F
AVERAGE LINER TEMPERATURE
MAXIMUM LINER TEMPERATURE
SYMBOL
ENERGY INPUT
○ 190 B.T.U./LB. AIR
● 240 B.T.U./LB. AIR
LUMINOMETER NUMBER
VS
LINER TEMPERATURE
850°F INLET AIR TEMP.
AERONAUTICAL ENGINE LABORATORY
NAVAL AIR MATERIAL CENTER, PHILADELPHIA 12, PA.
P. A. NAM RAPP 41017 Engr. Mc CLELLAND


PLATE 8

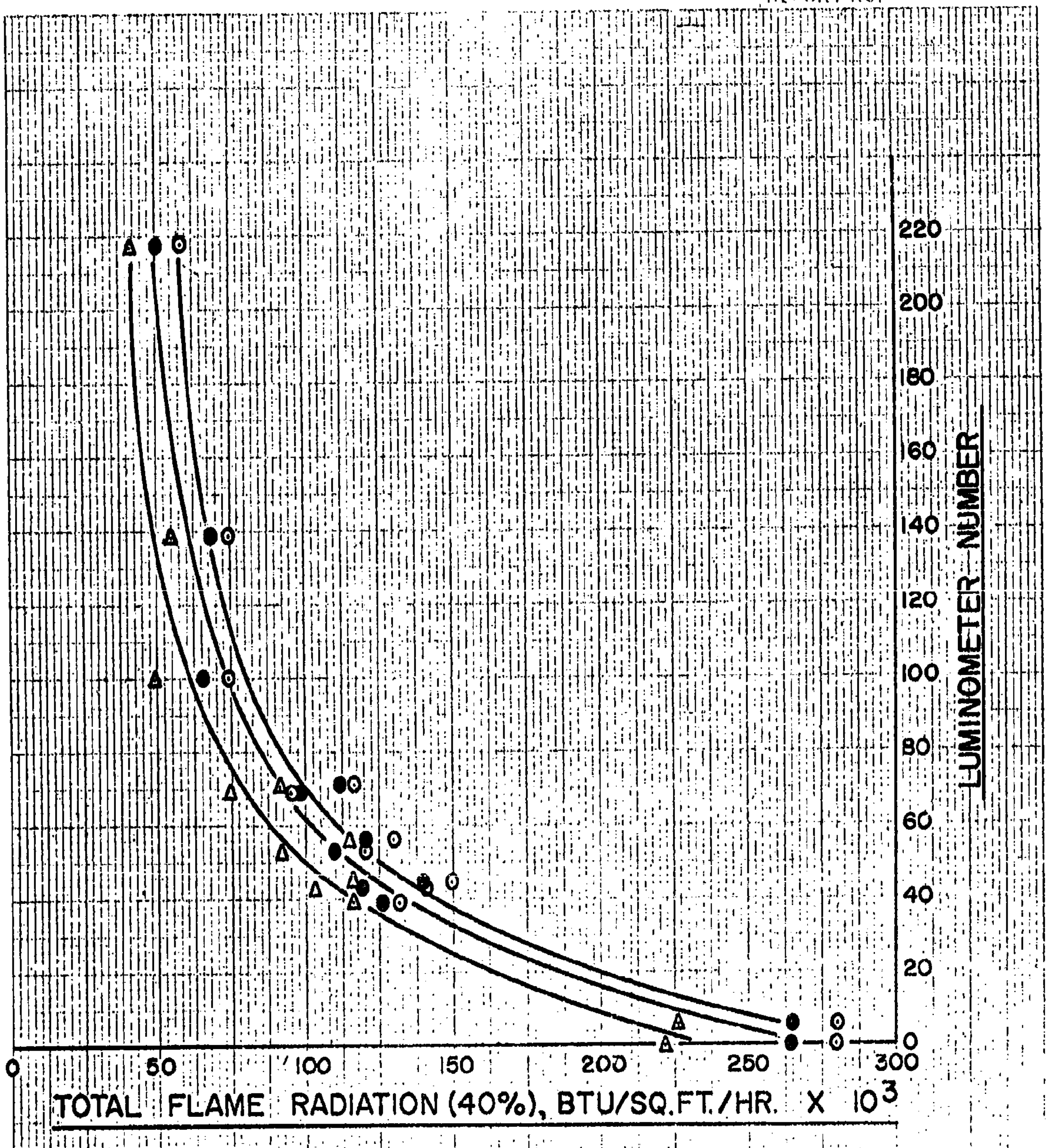
REPORT NO.




LUMINOMETER NUMBER
VS
LINER TEMPERATURE
190 BTU/LB. AIR

P. A. NAM RAPP 41017 ENG'R Mc CLELLAND

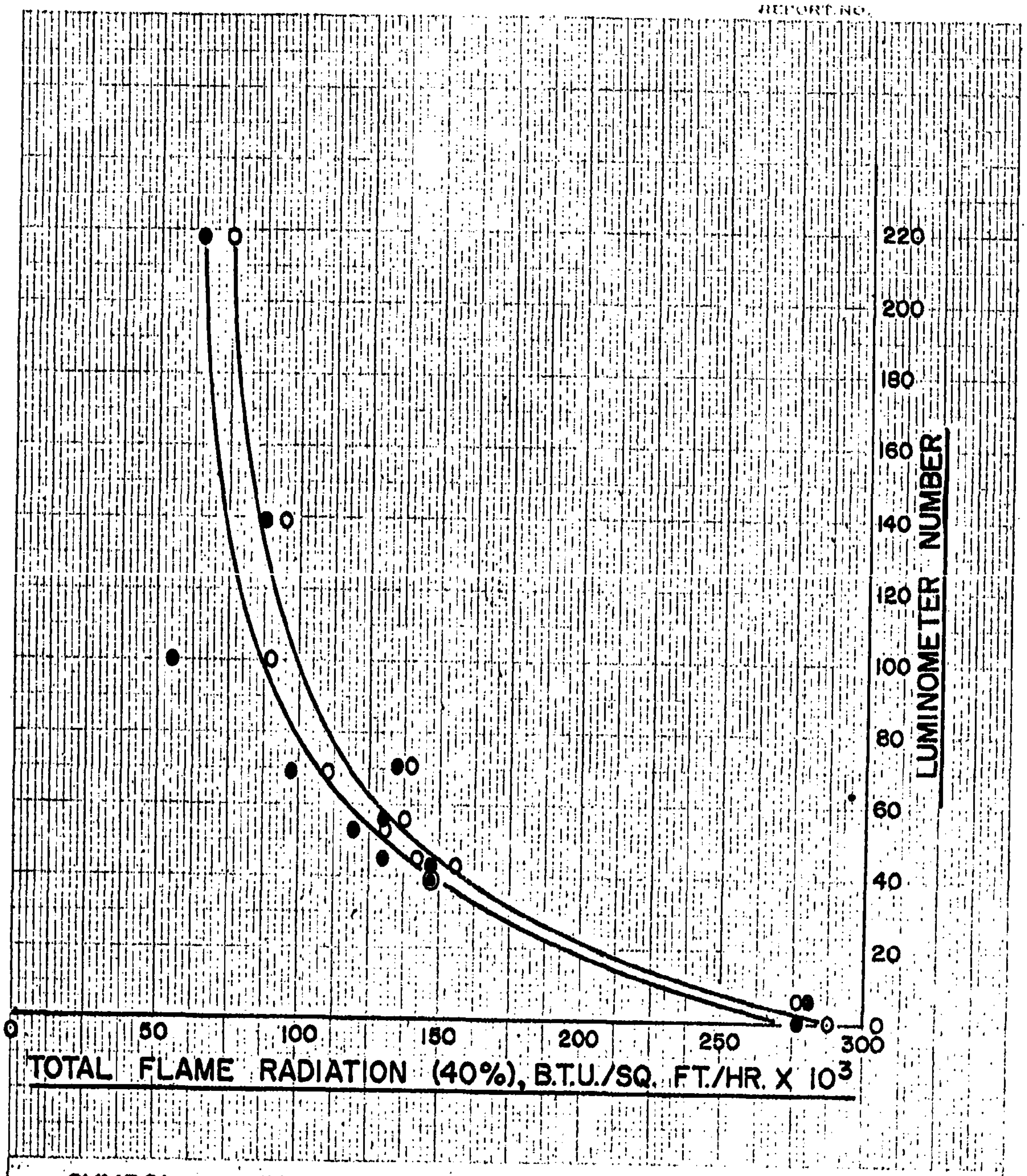
REPORT NO.




| SYMBOL | ENERGY INPUT |
| --- | --- |
| ⊙ | 190 B.T.U./LB. AIR |
| ● | 240 B.T.U./LB. AIR |
| Δ | 280 B.T.U./LB. AIR |

LUMINOMETER NUMBER
VS
TOTAL FLAME RADIATION
530°F INLET AIR TEMPERATURE

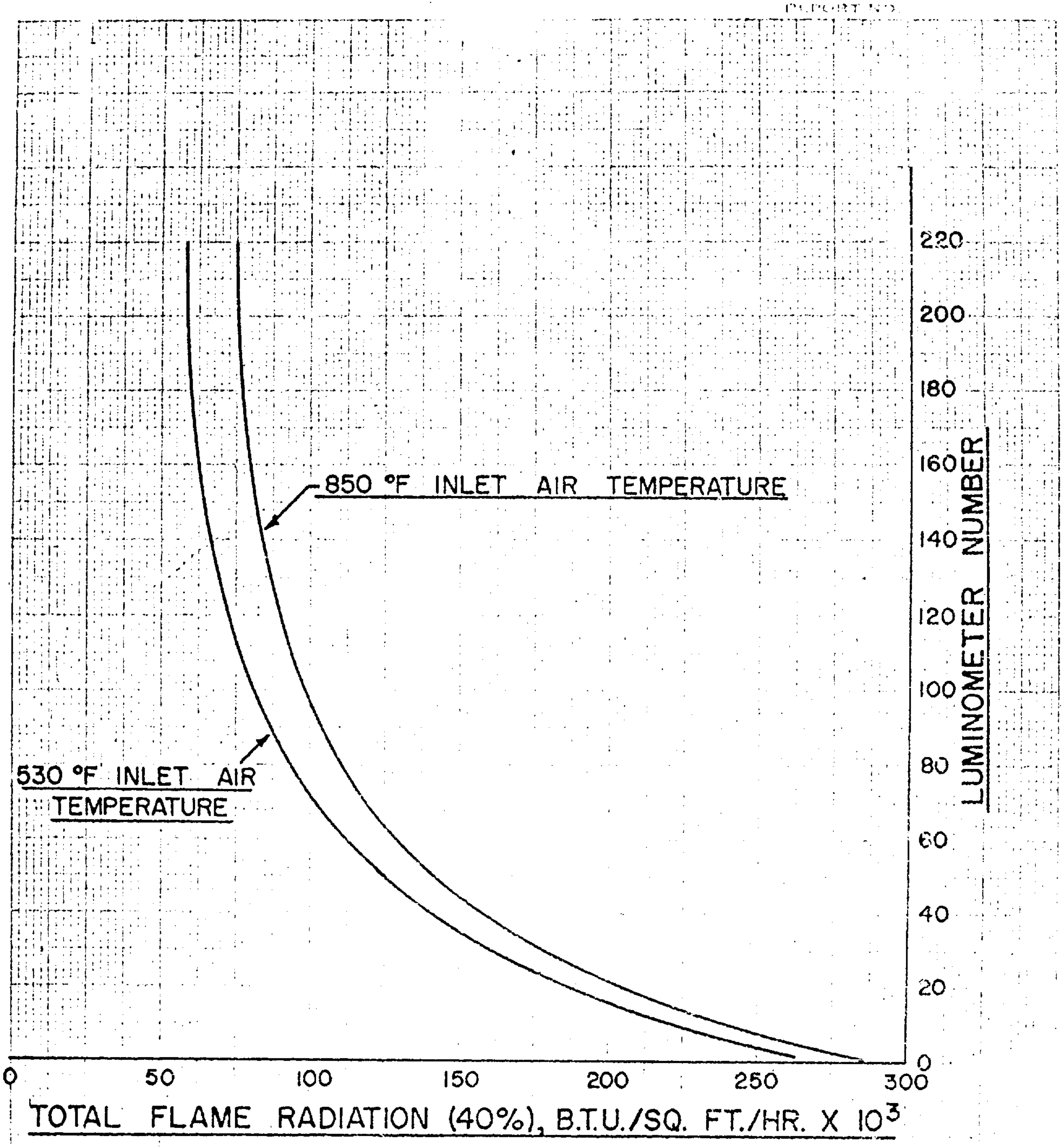
RAPP 41017 Mc CLELLAND




| SYMBOL | ENERGY INPUT |
|---|---|
| o | 190 B.T.U./LB. AIR |
| ● | 240 B.T.U./LB. AIR |

**LUMINOMETER NUMBER**
**VS.**
**TOTAL FLAME RADIATION**
**850°F INLET AIR TEMP.**

RAPP 41017 Mc CLELLAND




LUMINOMETER NUMBER
VS.
TOTAL FLAME RADIATION
190 B.T.U/LB. AIR

RAPP 41017 Mc CLELLAND

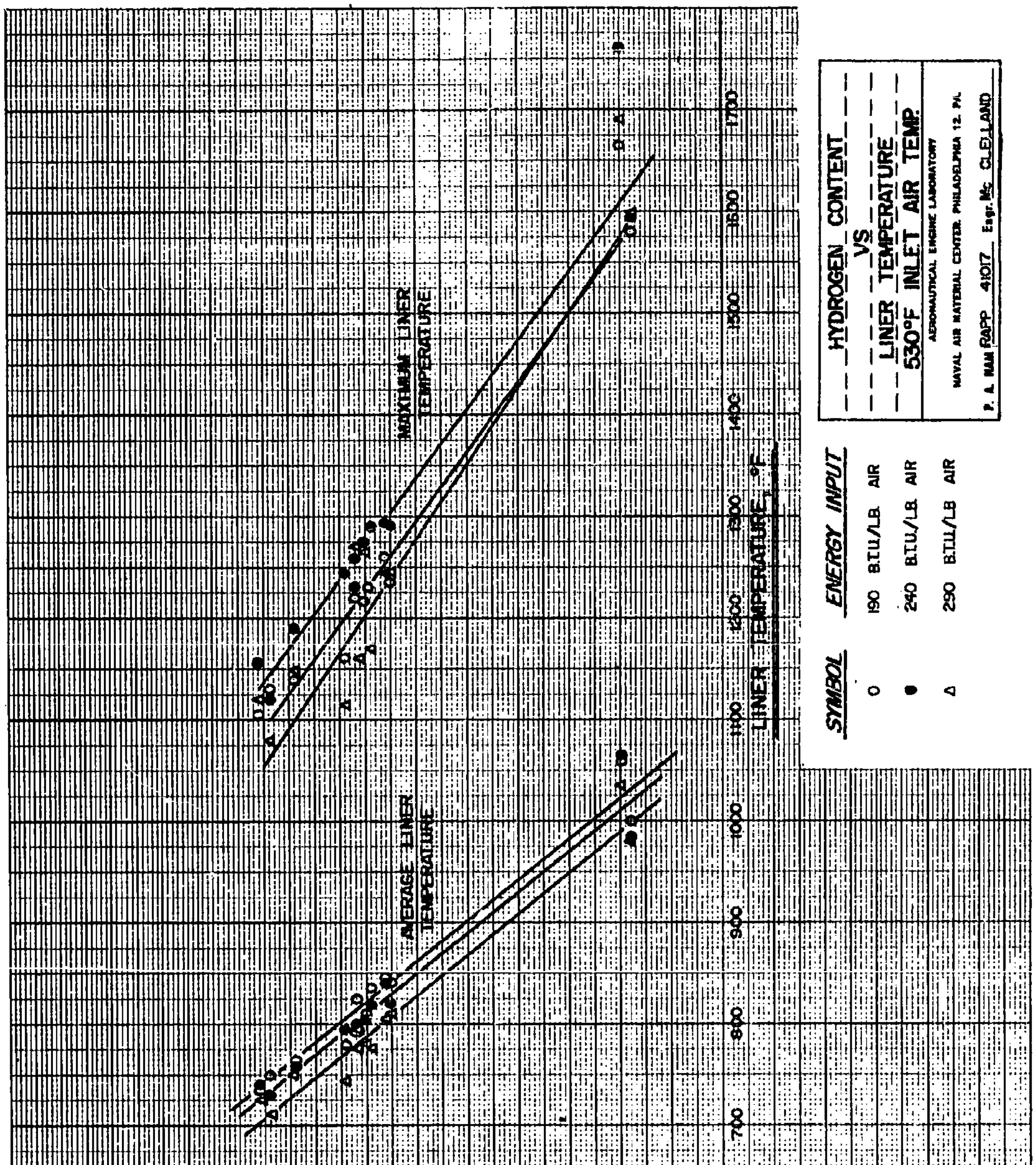
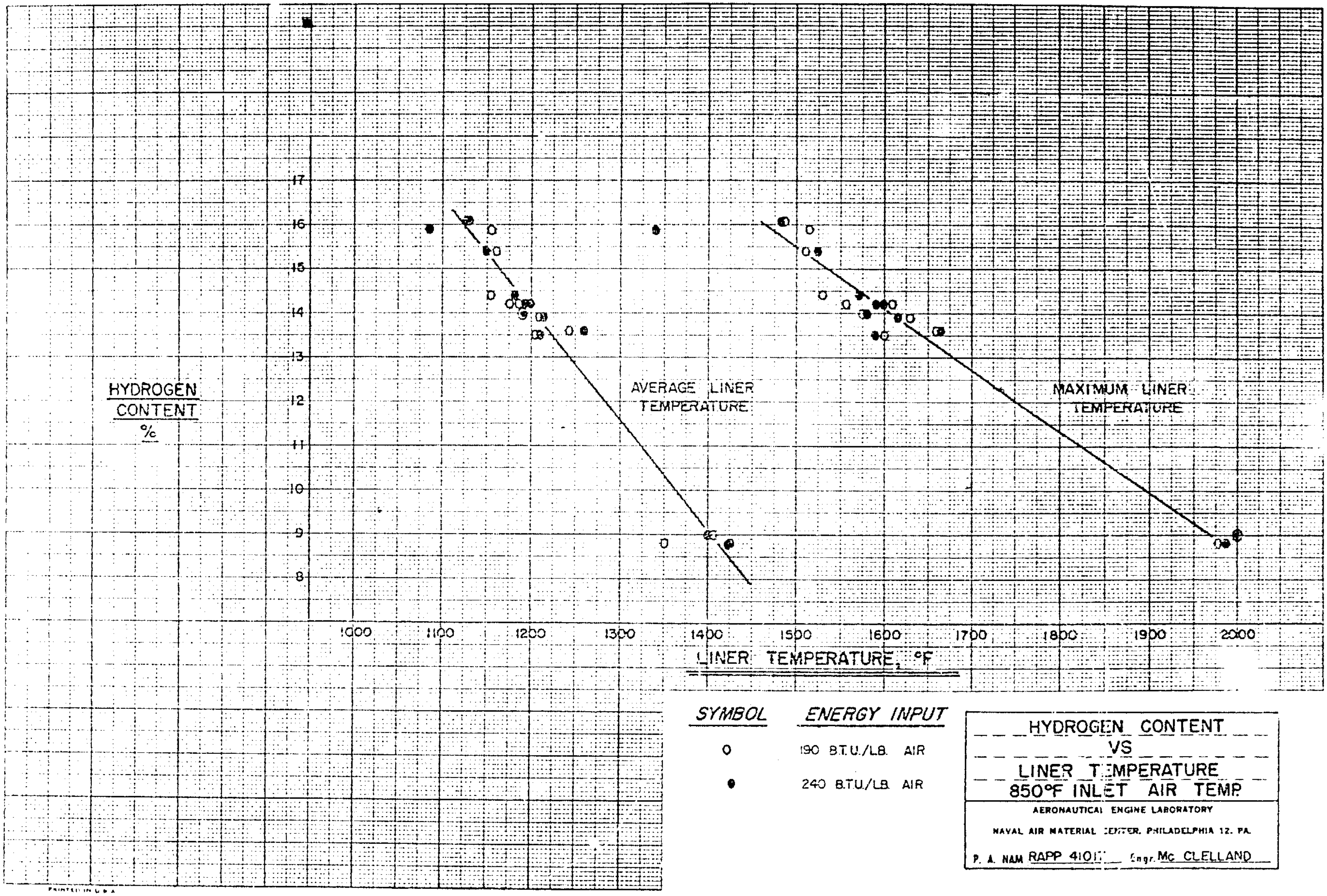

HYDROGEN CONTENT
VS
LINER TEMPERATURE
530°F INLET AIR TEMP.
AERONAUTICAL ENGINE LABORATORY
NAVAL AIR MATERIAL CENTER, PHILADELPHIA 12, PA.
SYMBOL
ENERGY INPUT
190 B.T.U./LB. AIR
240 B.T.U./LB. AIR
290 B.T.U./LB AIR
HYDROGEN CONTENT %
LINER TEMPERATURE, °F
MAXIMUM LINER TEMPERATURE
AVERAGE LINER TEMPERATURE
8
9
10
11
12
13
14
15
16
17
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700

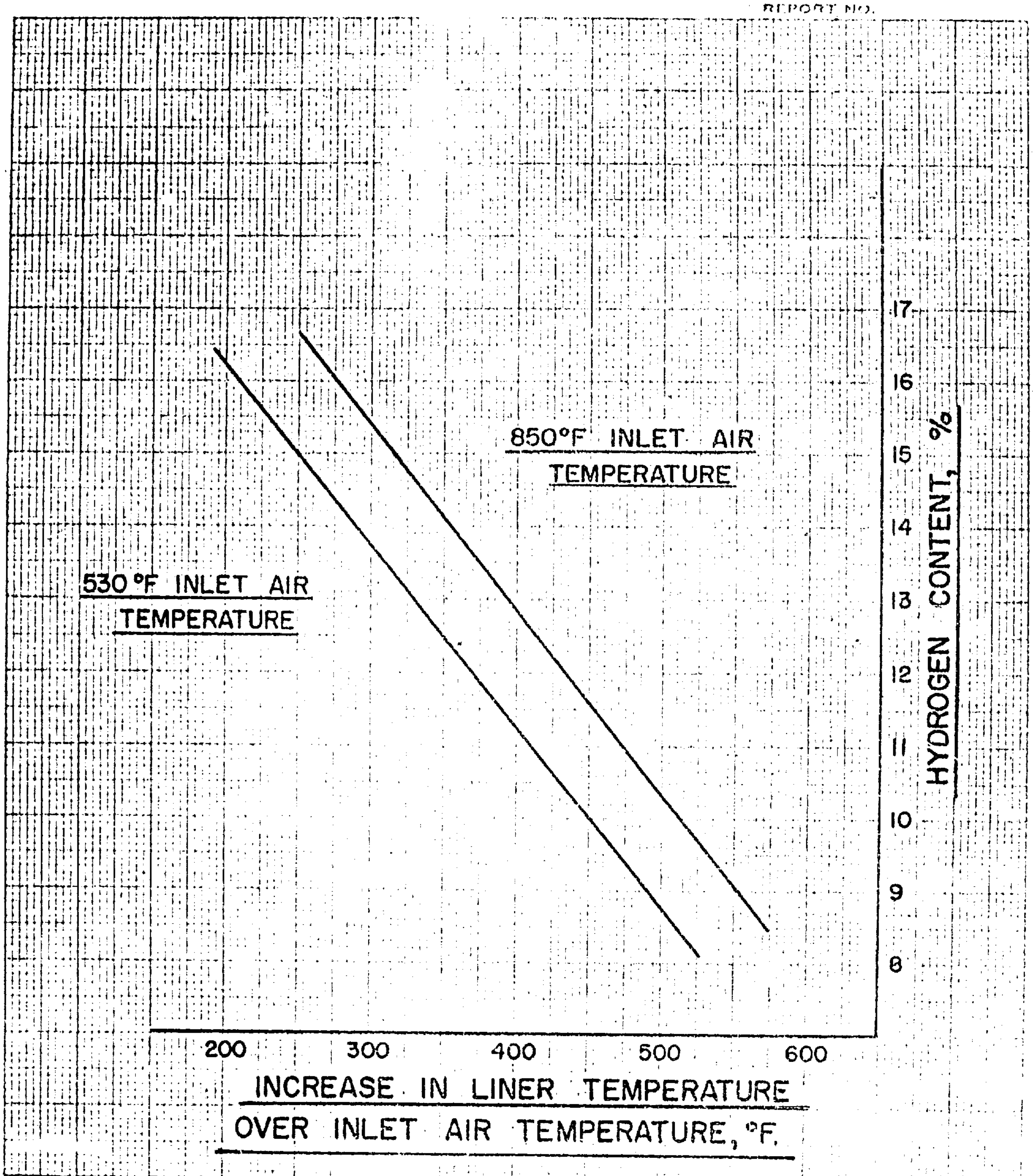
PLATE 13



HYDROGEN CONTENT %
17
16
15
14
13
12
11
10
9
8
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
LINER TEMPERATURE, °F
AVERAGE LINER TEMPERATURE
MAXIMUM LINER TEMPERATURE
SYMBOL
ENERGY INPUT
190 B.T.U./LB. AIR
240 B.T.U./LB. AIR
HYDROGEN CONTENT
VS
LINER TEMPERATURE
850°F INLET AIR TEMP.
AERONAUTICAL ENGINE LABORATORY
NAVAL AIR MATERIAL CENTER, PHILADELPHIA 12, PA.
P. A. NAM RAPP 4101 Engr. Mc CLELLAND

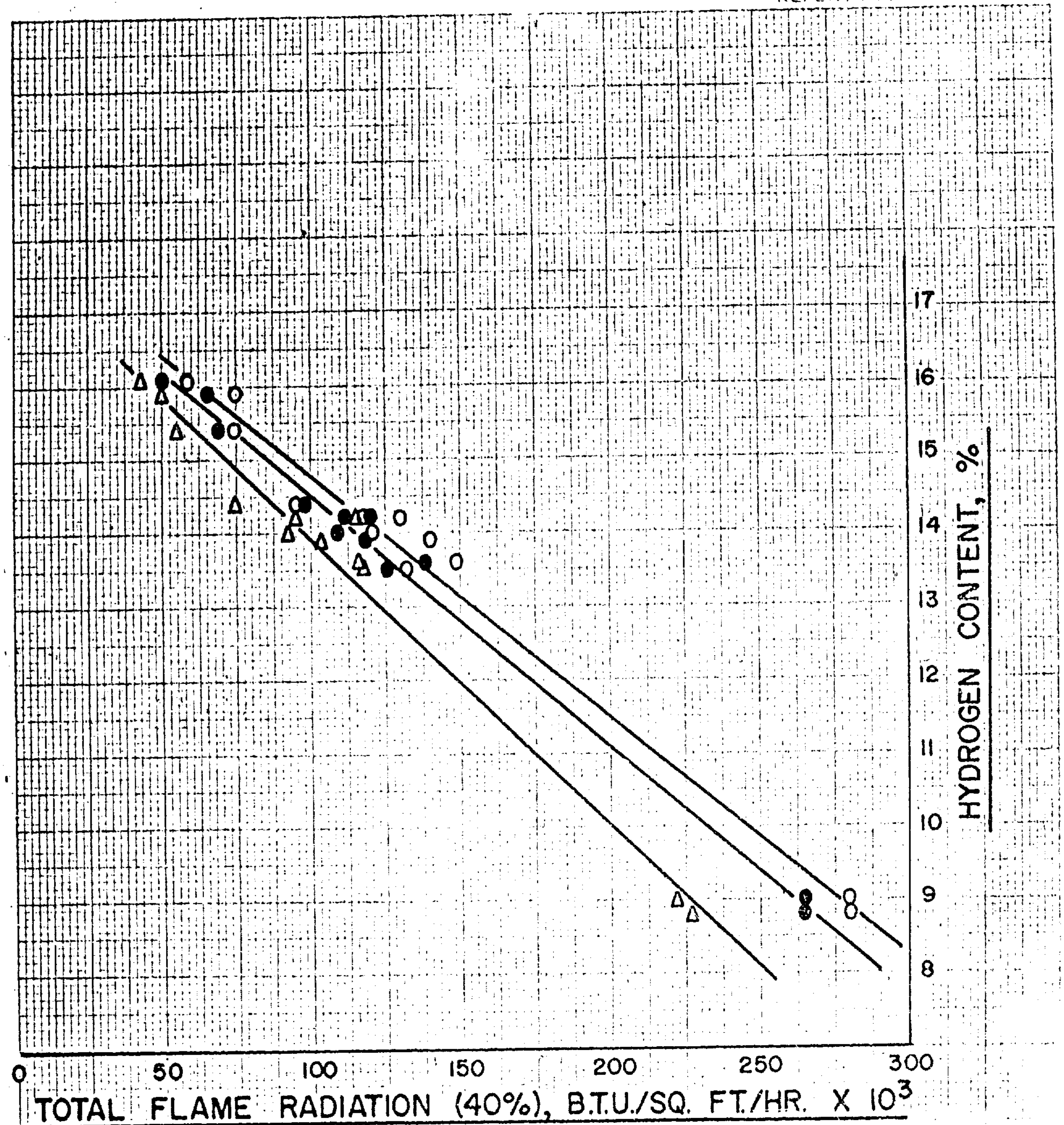

PLATE 14

REPORT NO.




HYDROGEN CONTENT
VS.
LINER TEMPERATURE
190 B.T.U./LB. AIR

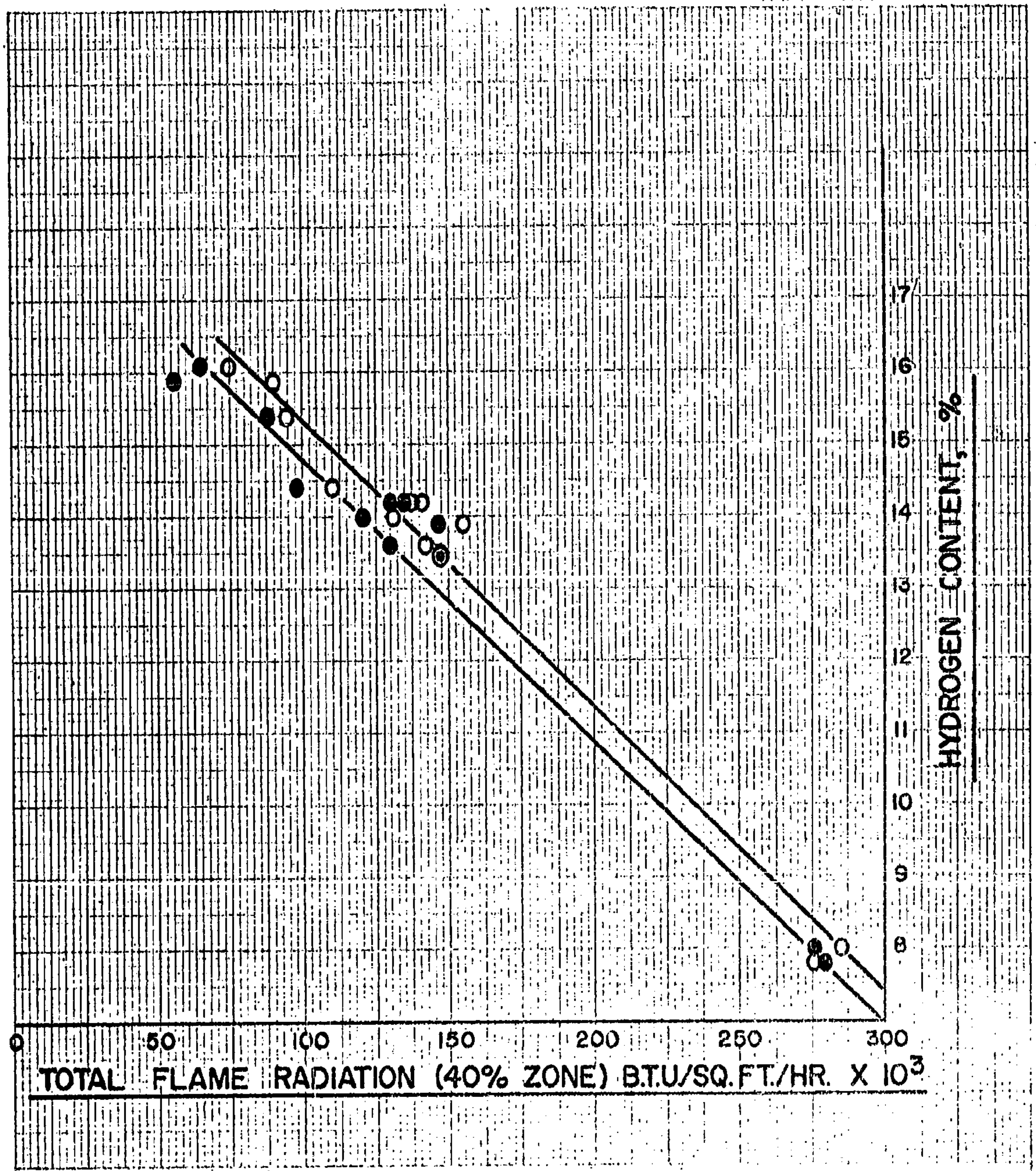
RAPP 41017 Mc CLELLAND




| SYMBOL | ENERGY INPUT |
|---|---|
| O | 190 B.T.U./LB. AIR |
| ● | 240 B.T.U./LB AIR |
| Δ | 280 B.T.U./LB. AIR |

HYDROGEN CONTENT
VS
TOTAL FLAME RADIATION
530 °F INLET AIR TEMP.

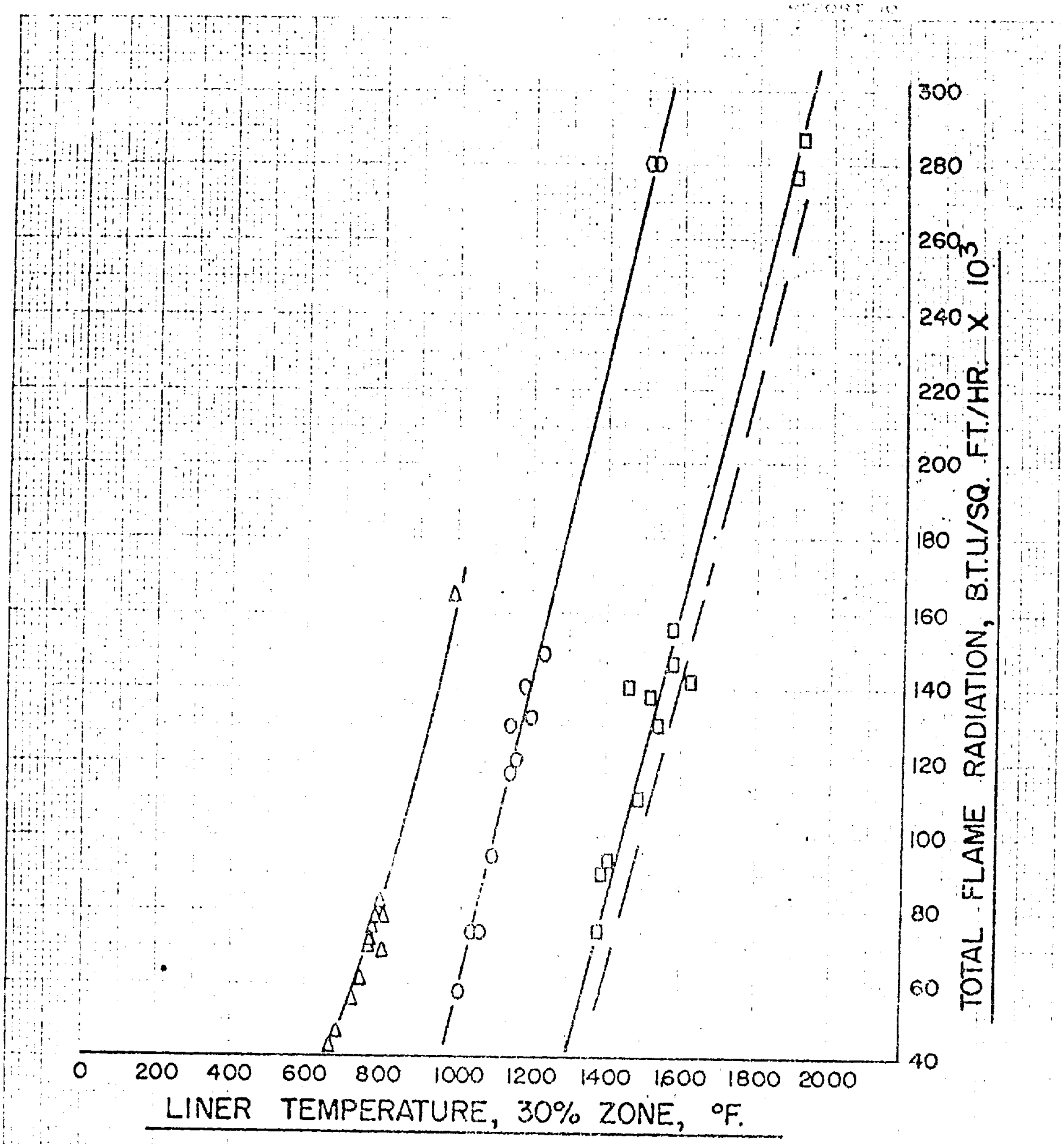
RAPP 41017 Mc CLELLAND




| ***SYMBOL*** | ***ENERGY INPUT*** |
|---|---|
| ○ | 190 B.T.U./LB. AIR |
| ● | 240 B.T.U./LB. AIR |

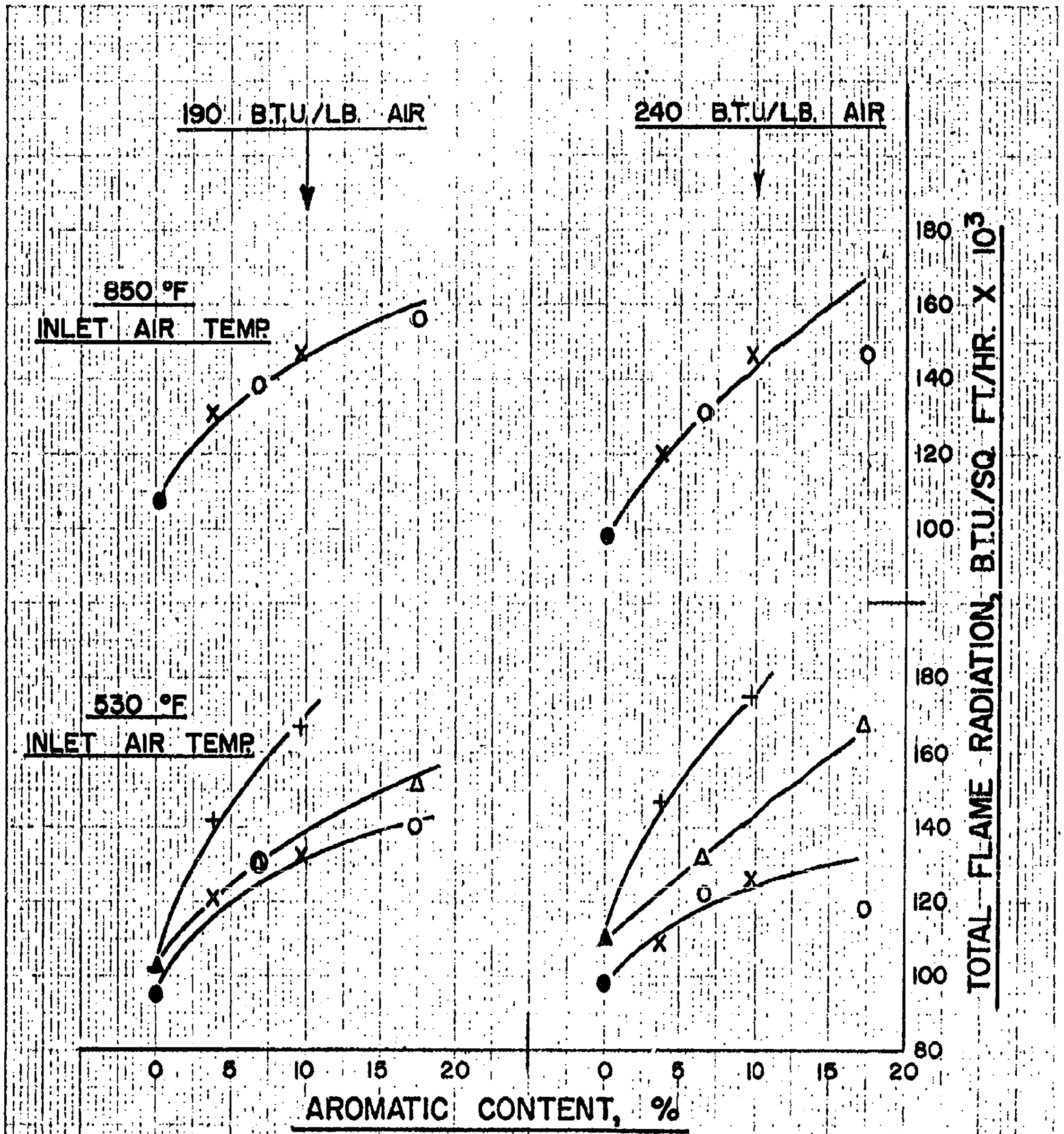
HYDROGEN CONTENT
VS
TOTAL FLAME RADIATION
850°F INLET AIR TEMP.

RAPP 41017 Mc CLELLAND




| SYMBOL | BURNER | INLET TEMP | RADIATION ZONE |
|---|---|---|---|
| O | J 79 | 530°F | 40 % |
| □ | J 79 | 850°F | 40% |
| Δ | J 57 | 540°F | 30% REF (3) |
| — — | PHILLIPS 2" | 540°F | 30% REF (5) |

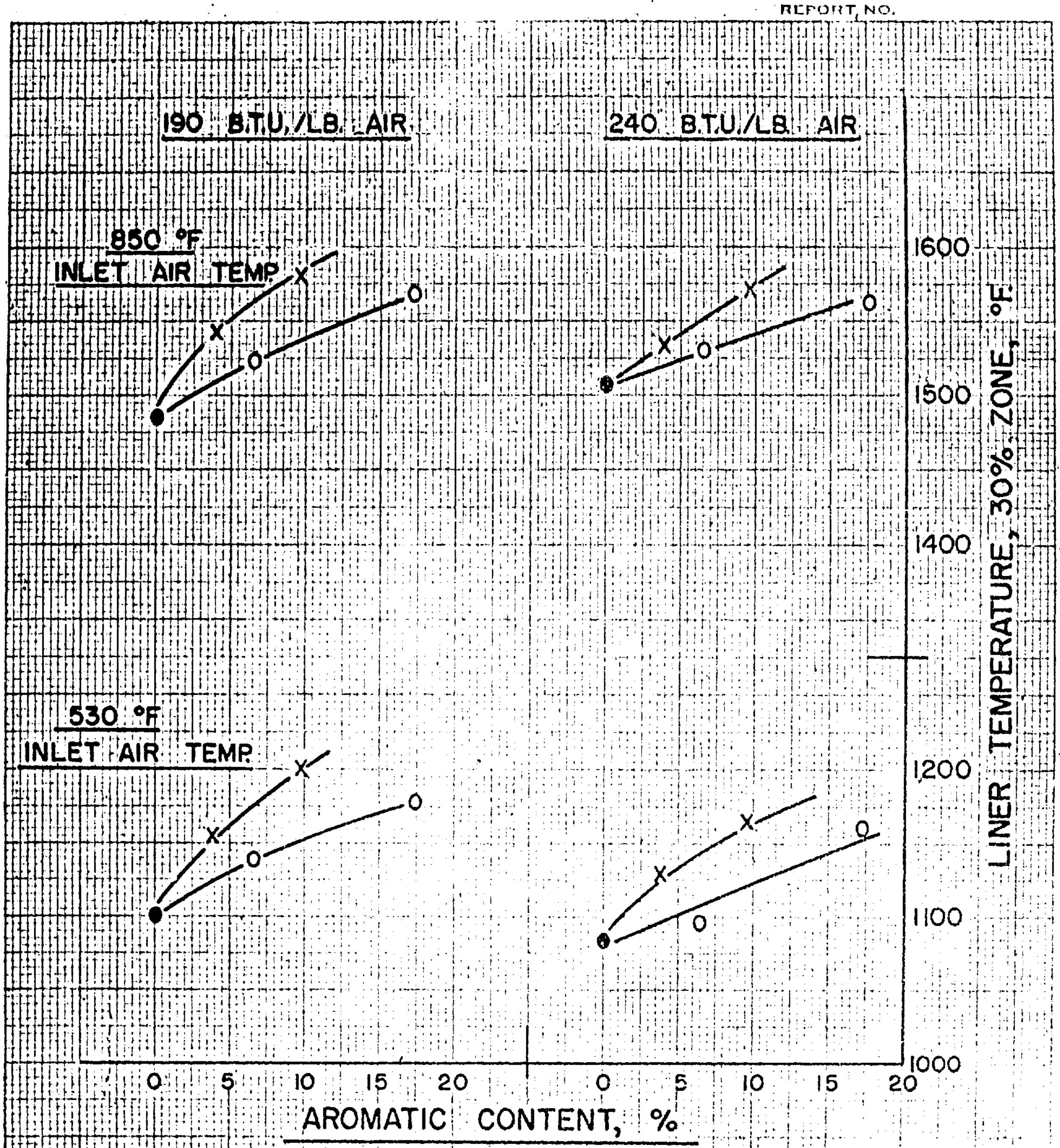
TOTAL FLAME RADIATION
VS
LINER TEMPERATURE
190 B.T.U./LB. AIR




| RADIATION ZONE 40% | RADIATION ZONE 65% | FUEL |
|---|---|---|
| ● | ▲ | BASE |
| O | Δ | BASE + MONOCYCLIC AROM. |
| X | + | BASE + POLYCYCLIC AROM. |

**EFFECT OF AROMATIC STRUCTURE ON TOTAL RADIATION**

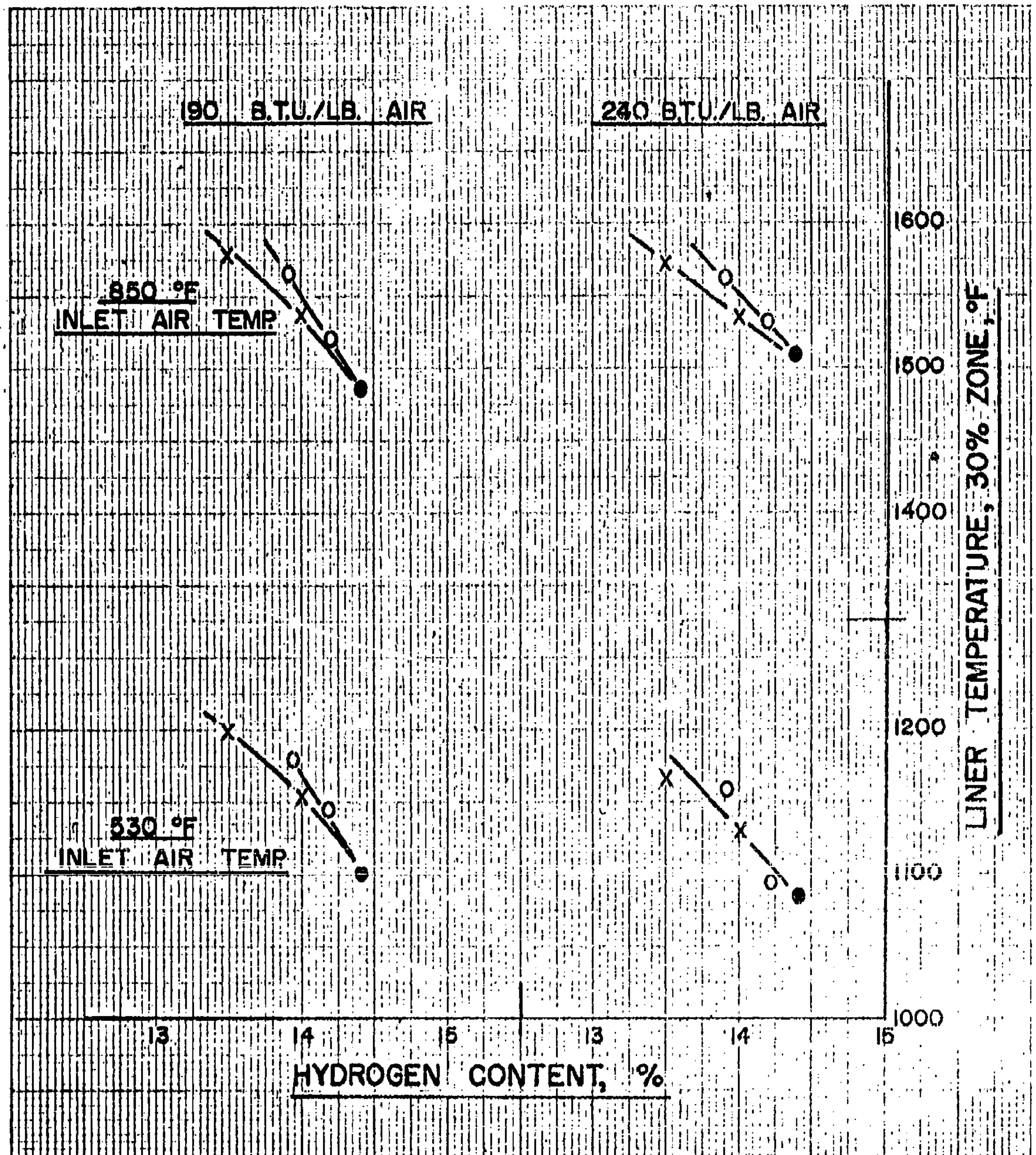
RAPP 41017 Mc CLELLAND




| SYMBOL | FUEL |
|---|---|
| ● | BASE |
| O | BASE + MONOCYCLIC AROM. |
| X | BASE + POLYCYCLIC AROM. |

EFFECT OF AROMATIC STRUCTURE-
LINER TEMPERATURE
VS
AROMATIC CONTENT

RAPP 41017 Mc CLELLAND

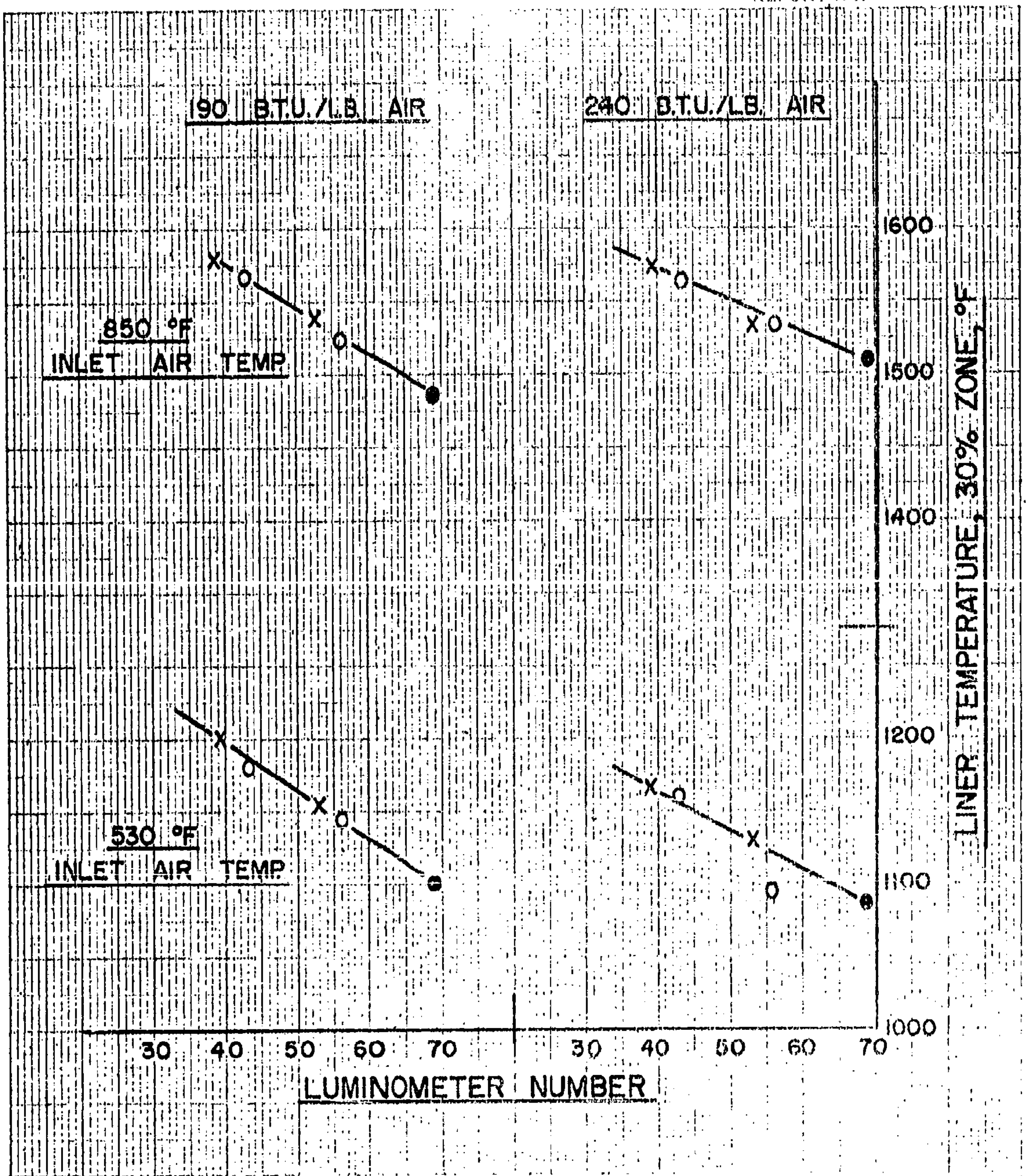



| SYMBOL | FUEL |
|---|---|
| ● | BASE |
| O | BASE + MONOCYCLIC AROM. |
| X | BASE + POLYCYCLIC AROM. |

**EFFECT OF AROMATIC STRUCTURE-**
**LINER TEMPERATURE**
**VS**
**HYDROGEN CONTENT**

P. A. NAM RAPP 41017 Mc CLELLAND

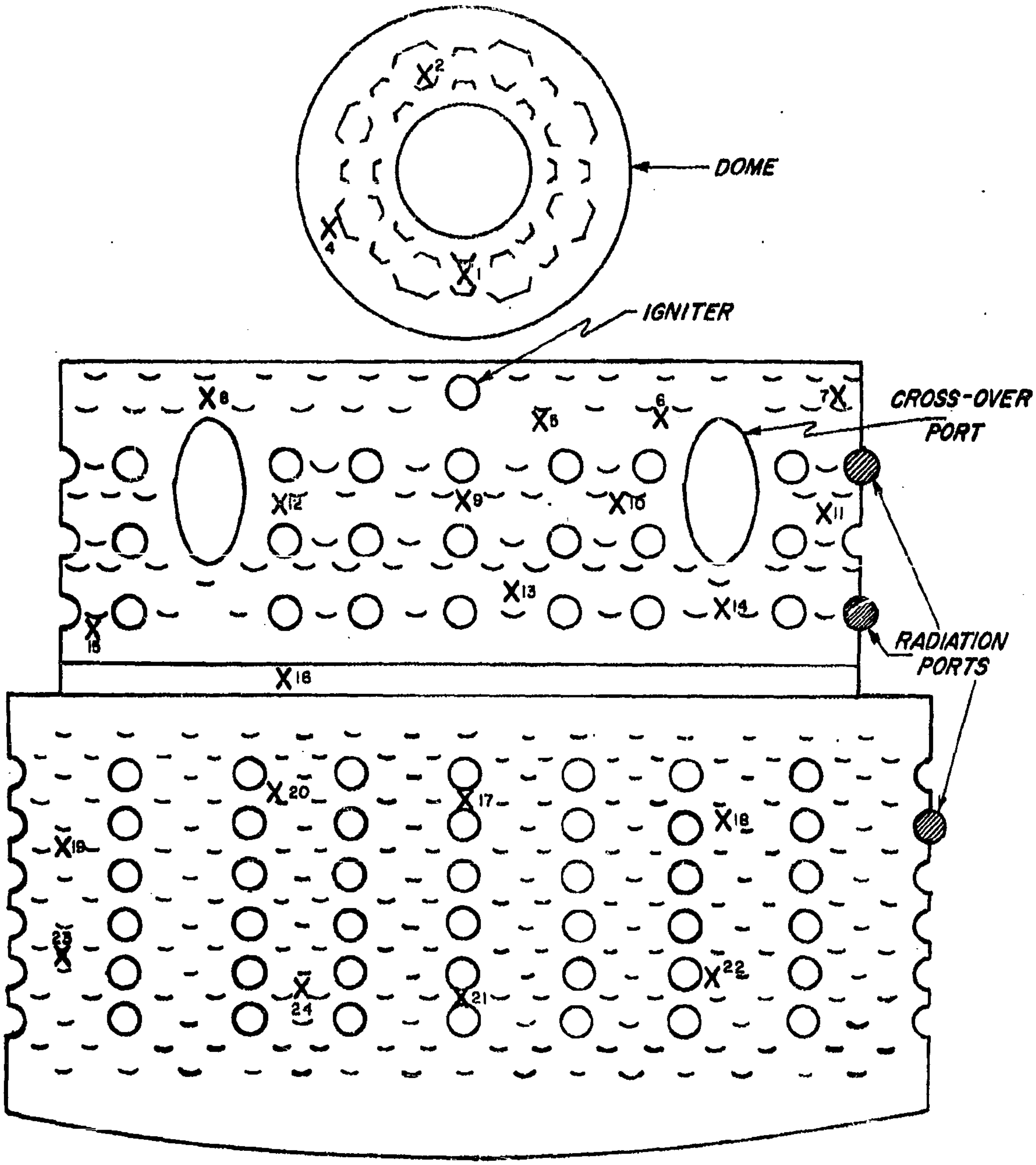
PLATE 21




| *SYMBOL* | *FUEL* |
|---|---|
| ● | BASE |
| O | BASE + MONOCYCLIC AROM. |
| X | BASE + POLYCYCLIC AROM. |

EFFECT OF AROMATIC STRUCTURE
- LINER TEMPERATURE
VS
LUMINOMETER NUMBER

RAPP 41017 Mc CLELLAND



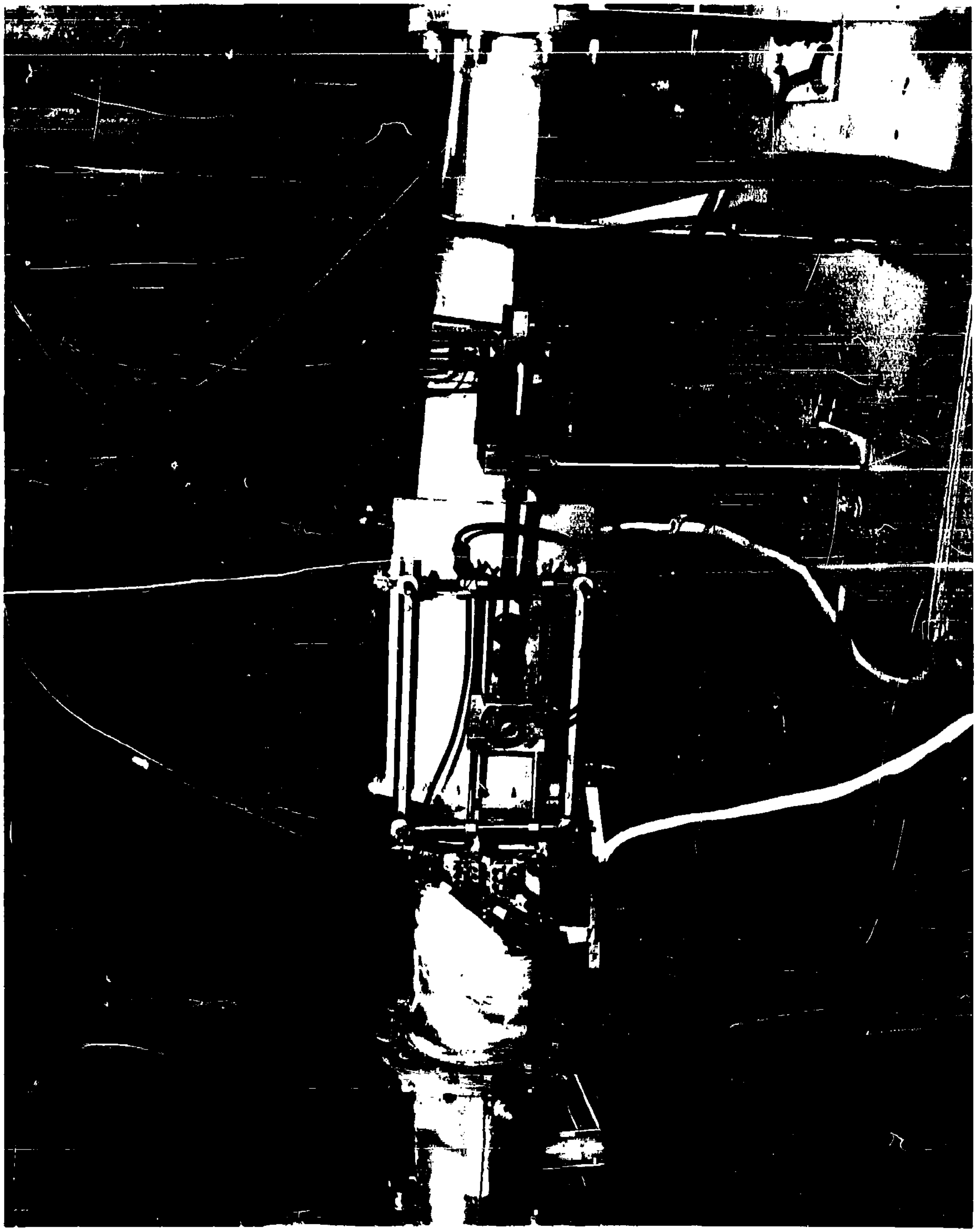

**J79 COMBUSTOR LINER**
**PLAN VIEW SHOWING**
**THERMOCOUPLE & RADIATION**
**MEASUREMENT LOCATIONS**

AERONAUTICAL ENGINE LABORATORY

NAVAL AIR MATERIAL CENTER, PHILADELPHIA 12, PA.

P. A. NAM RAPP 41017 Engr. Mc CLELLAND

PLATE 23



J79 SINGLE COMBUSTOR TEST SECTION

PHOTO NO: CAN-341019(L)-12-61

PLATE 24