LPC Report No. 578-P-13

THERMAL GRAIN STRUCTURAL ANALYSIS

Prepared by

LOCKHEED PROPULSION COMPANY
Redlands, California

Program Progress Report No. 13

Contract No. AF 04(611)-8013
LPC MPO 578

Period Covered

1 December through 31 December 1962

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FIGURES

I. INTRODUCTION

Lockheed Propulsion Company was authorized by Contract AF 04(611)-8013 to conduct a thermal grain structural analysis program.

Program Progress Report No. 13 is submitted in accordance with Paragraph 2.2 of AFBM Exhibit 58-1 in partial fulfillment of the contract requirements. This report is a brief resume of program progress under Lockheed Propulsion Company MPO 578 during the period from 1 December to 31 December 1962.

Effort during the current month was concentrated on computer determination of stresses in thermally cycled propellant grains, in ~~continuation of previous~~ work. Parametric thermal stress data for grains with varying dimensions subjected to step thermal conditioning and the results of rapid cooling tests of analogue motors are presented in this report.

II. PROGRAM PROGRESS

A. Thermoviscoelastic Stress Analysis

A series of IBM 7090 computer calculations were made for the purpose of establishing the influence of web fraction, grain diameter, and thermal change magnitude on the peak stresses obtained as a result of step temperature environment changes. The grain, as in previous calculations, was considered to be circularly perforated, under plane strain end constraint, incompressible, and contained in a rigid case. A step change in case temperature was assummed. Preliminary data for the port hoop stress and the case-grain interface pressure, based on a 1-foot diameter grain are shown in Figures 1 through 4. The calculations considered the following parametric variations:

- Thermal step inputs of -40^0, -100^0, -130^0, and -160^0F from a reference temperature of 70^0F.
- Web fractions of 9, 50, 66.7, 75, and 80 percent.

Peak stresses for various motor diameters can be determined from the data in Figures 1 through 4 in the following manner:

- Obtain the stress to σ_0 for a given λ (grain O. D. to I. D. ratio) and a particular grain O. D., b_0.
- For a new grain O. D. = b_1, the new stress value σ_1 is obtained as:

$$\sigma_1 = \sigma_0 \left(\frac{b_1}{b_0}\right)^{-0.43}$$

The previous progress report of this series discussed additional effort directed at the problem of stress accumulation. The thermal inputs shown in Figure 5 were employed in IBM 7090 computer calculation of peak grain stresses. While the peak hoop stress at the port calculated for case I (Figure 5) was approximately two percent higher than that resulting from a simple step input, the difference is within the probable computer program accuracy.

B. Circular Port Analogue Motor Tests

Four of the 4-inch diameter by 14-inch long circular port analogue motors (cast from a batch of Polycarbutene-R propellant) previously mentioned (Ref. 1) were subjected to rapid cooling for determination of their failure behavior. The dimensional data for the motors are as follows:

Motor Number	Length/Diameter (in.)	Grain O. D./Grain I. D. (in.)
1	10/4	4/1.5
2	10/4	4/1.2
3	10/4	4/1.0
4	10/4	4/0.866

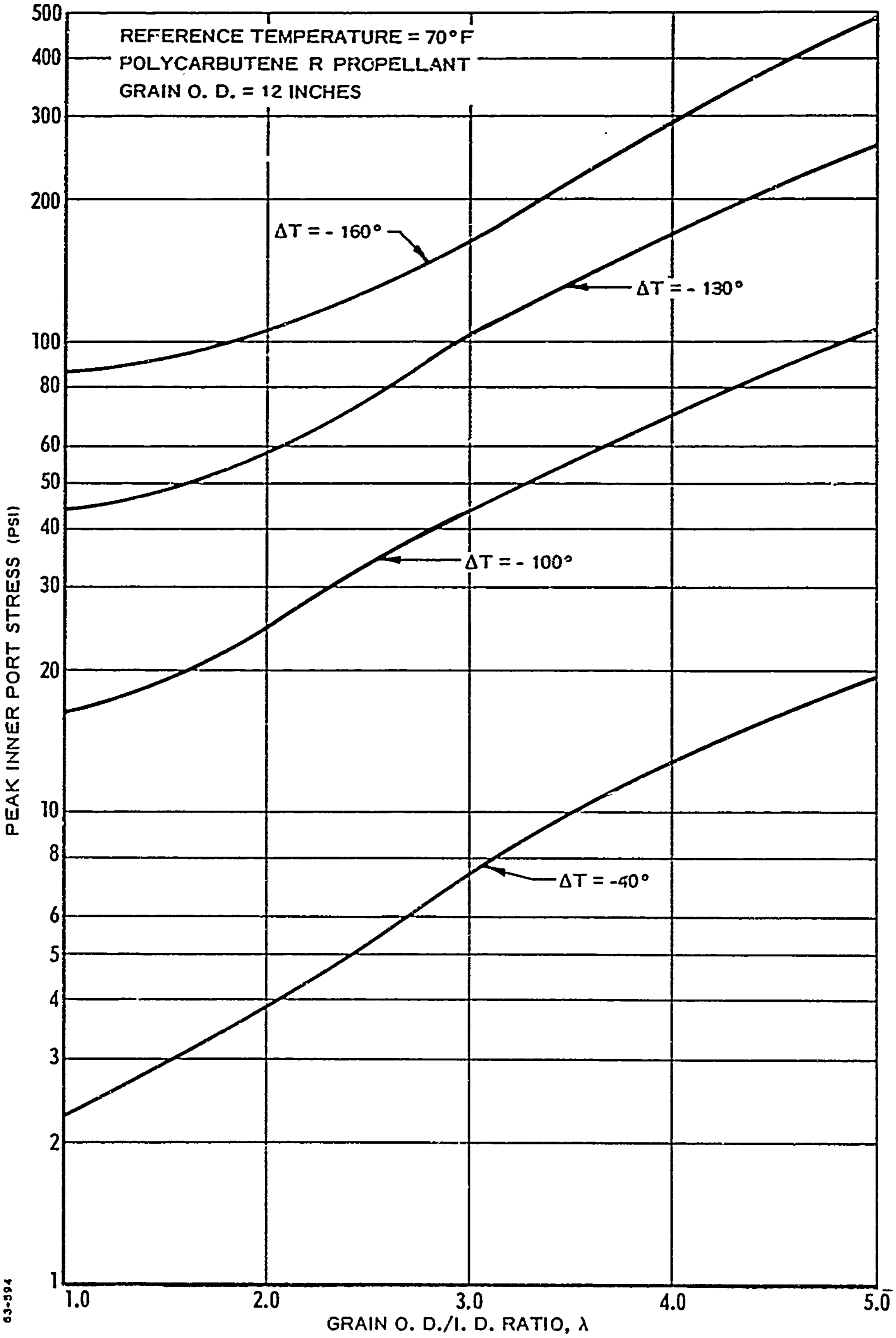

Figure 1 Peak Inner Port Hoop Stress versus Temperature and Grain O. D. to I. D. Ratio

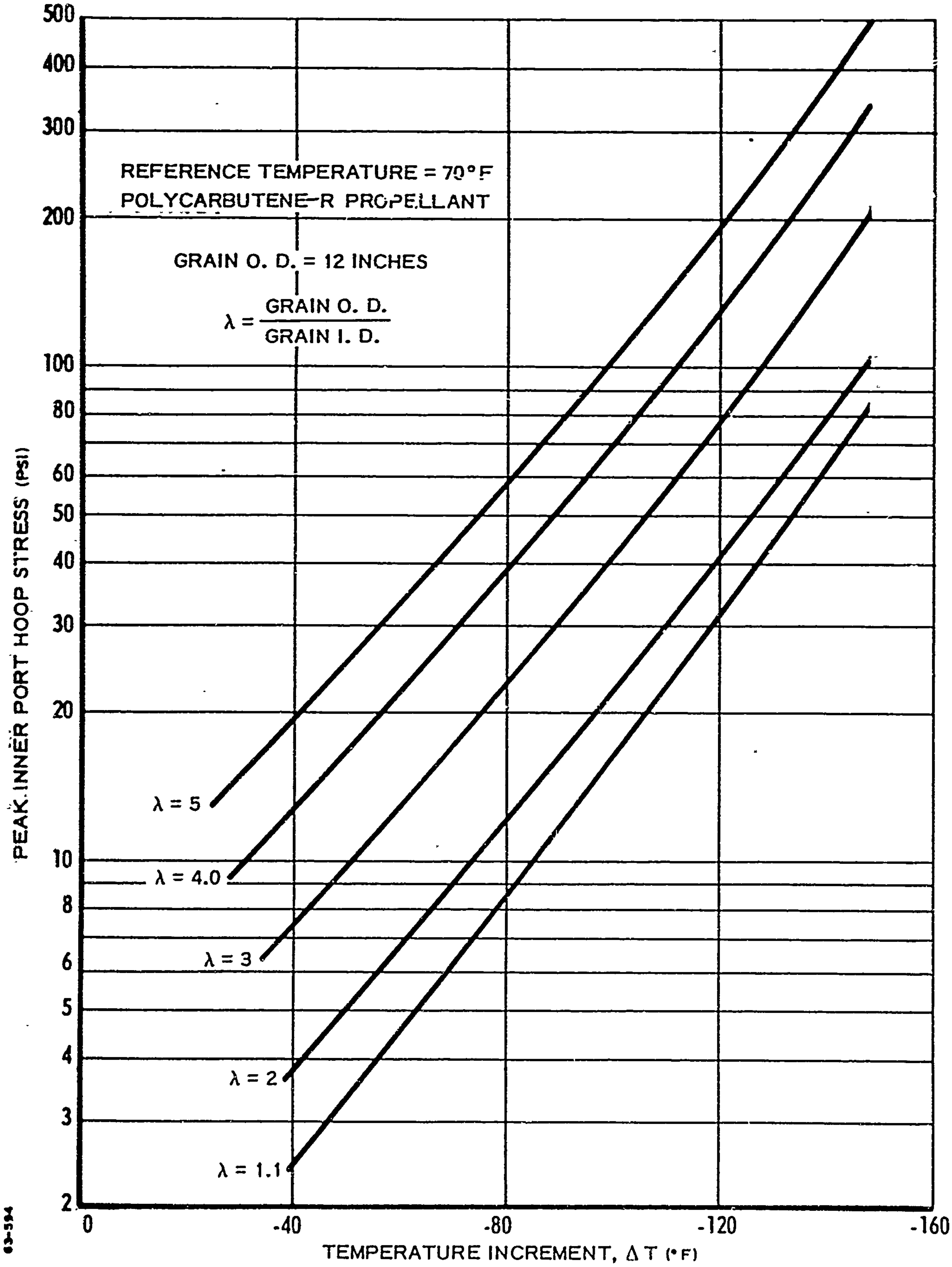

Figure 2 Peak Inner Port Hoop Stress versus Temperature and Grain O.D. to I.D. Ratio

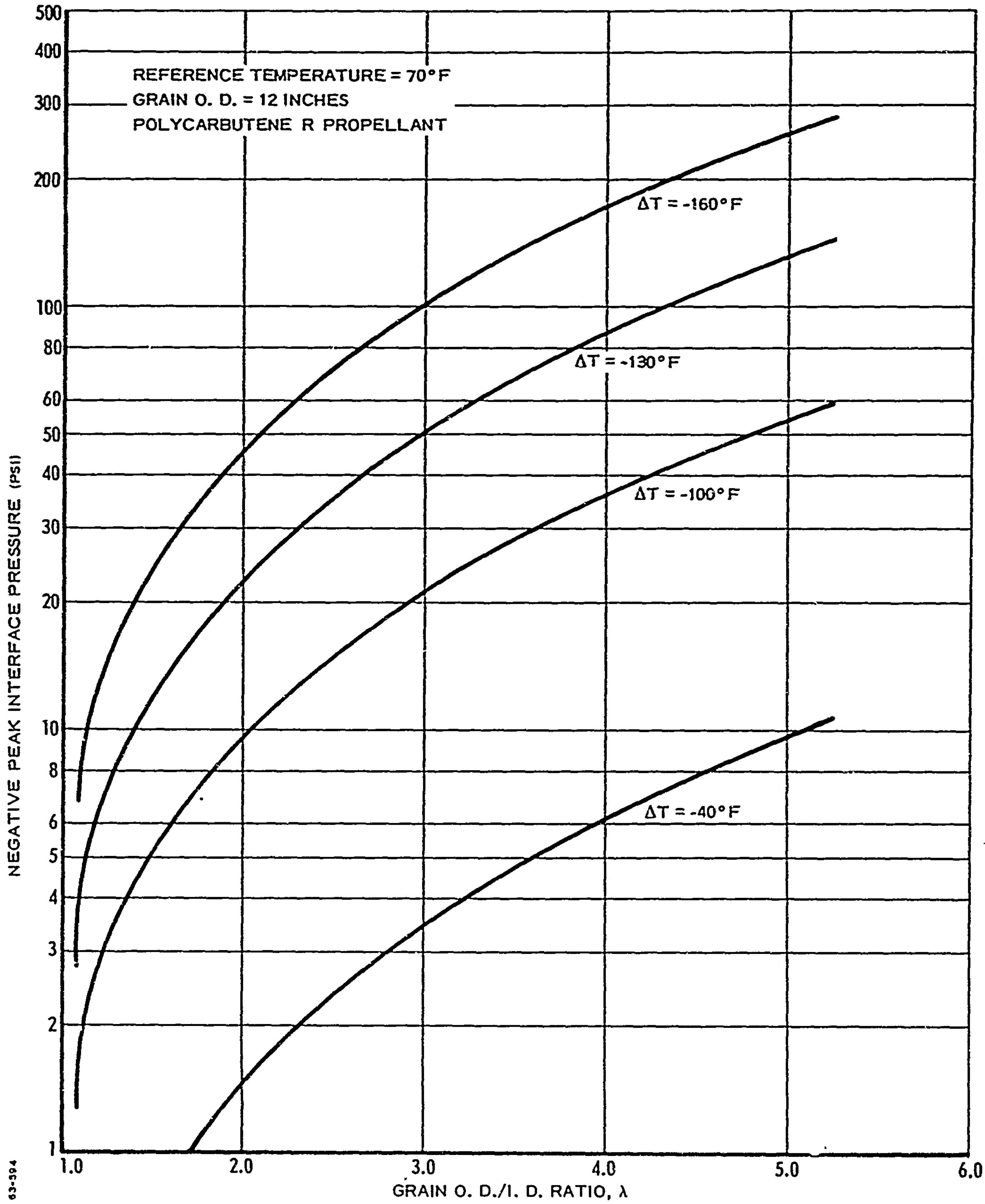

Figure 3 Case-Grain Interface Pressure versus Temperature and Grain O. D. to I. D. Ratio

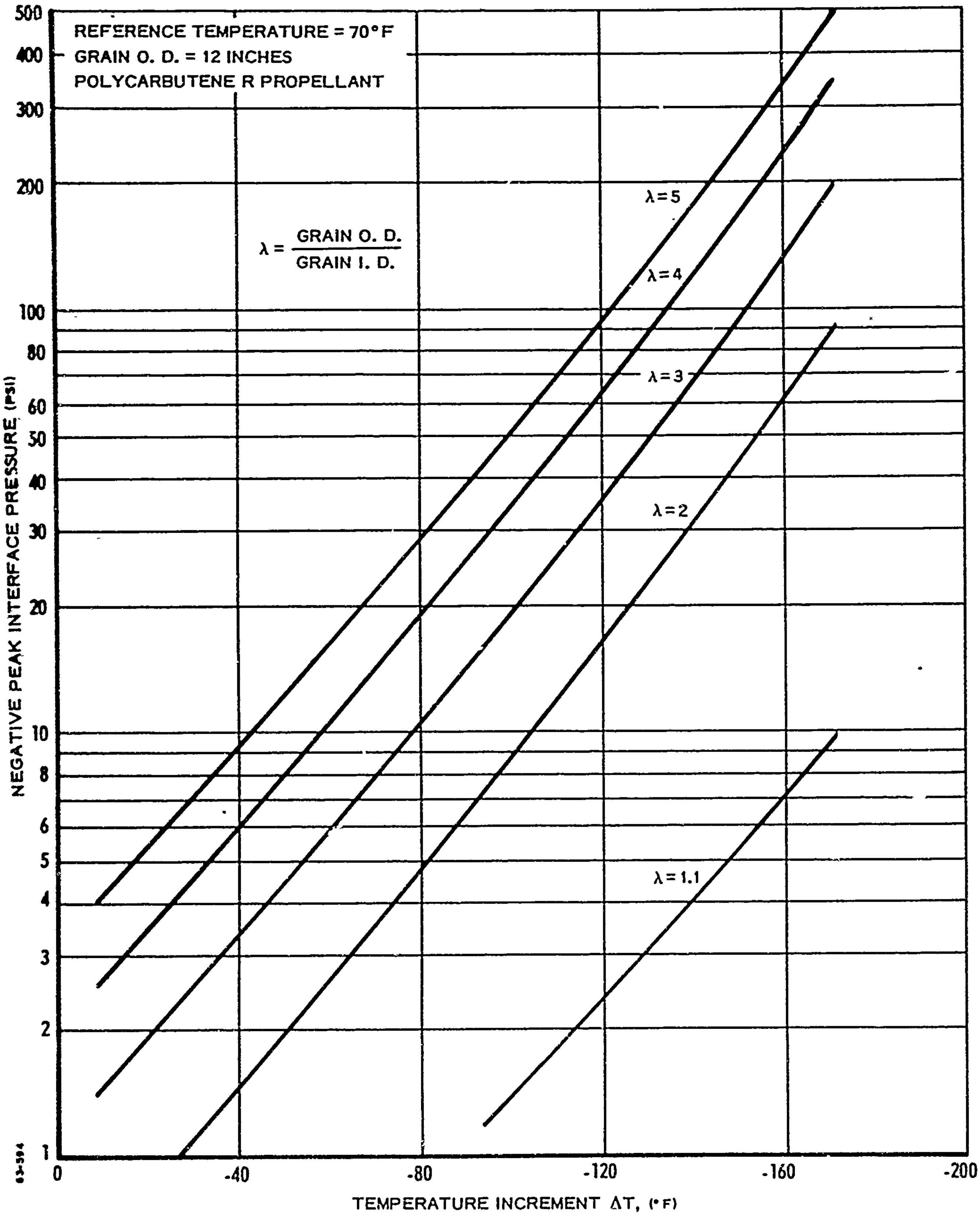

Figure 4 Case-Grain Interface Pressure versus Temperature and Grain O. D. to I. D. Ratio

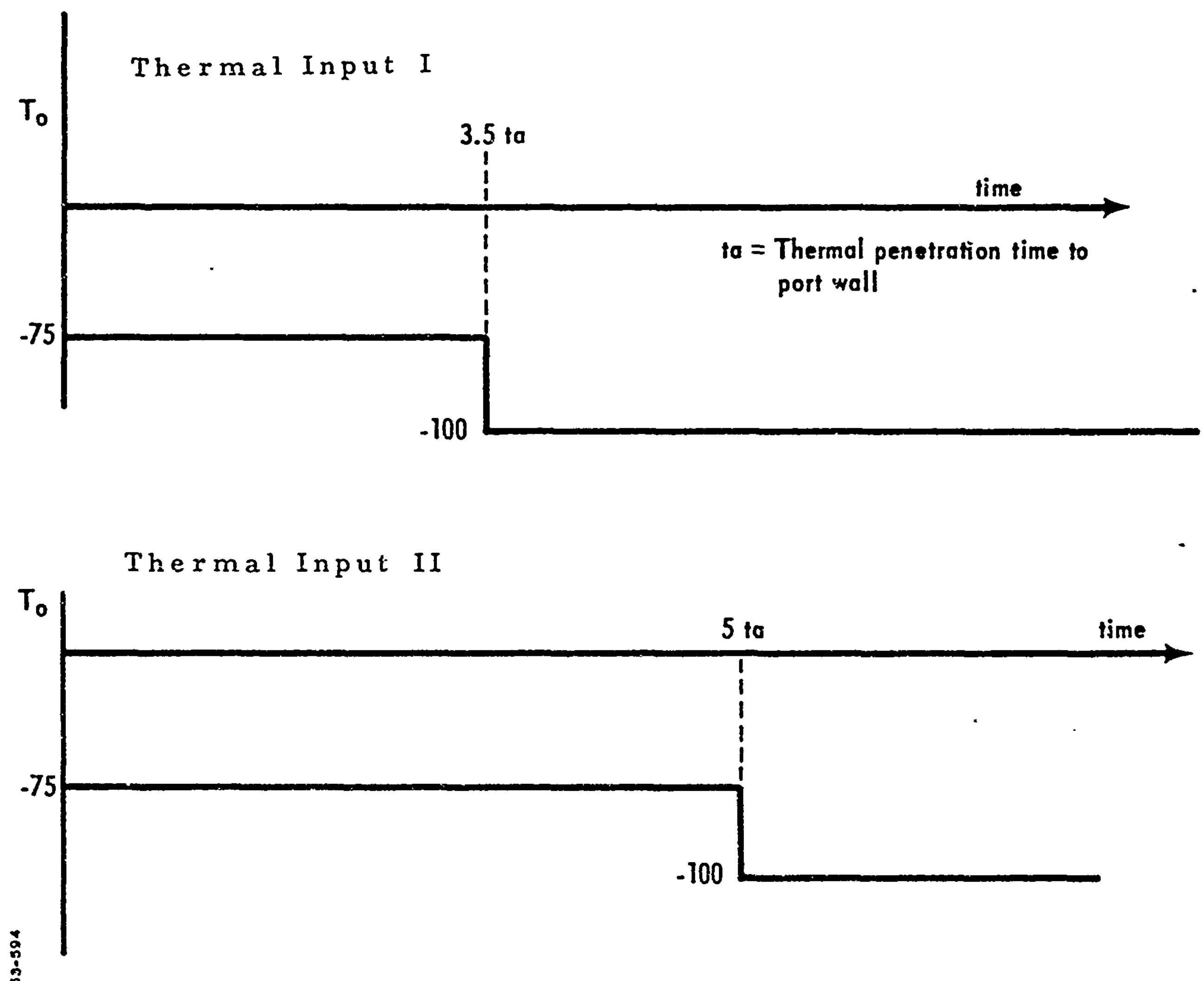

Figure 5 Thermal Inputs versus Time

The motors, held in 70°F dessicated storage for approximately 3 1/2 months, were inserted in a conditioning box previously stabilized at -75°F and cooled with the ambient box atmosphere (air and co_2) maintained at -75°F. The ends of the motors were closed and insulated to minimize axial heat flow. Port and exterior case temperatures were monitored with thermocouples, and the port hoop strains at the centerlines of the motors were measured periodically during the test.

The temperature and strain measurements are shown in Figures 6 through 9. Failures in the form of longitudinal cracks were observed as follows:

Motor No.	Failure temperature (port wall) (°F)
1	no failure at -75°
2	-60° to -65°
3	-40° to -50°
4	-35° to -45°

Assuming (in the limit) isothermal conditions in the grain, and taking the grain temperatures to be those measured at the port walls (Ref. 2), the failure temperatures correlated within 15°F to those predicted from uniaxial tensile test data.

The port temperature versus time for motor No. 3 was predicted by using an analytic approximation for the measured exterior case temperature as the heat input condition, and employing the thermal field analysis methods described in previous reports (Ref. 2, 3, and 4). Data for this calculation are shown in Figure 8; the agreement, as anticipated, was excellent.

Replicates of motors 1, 2, and 3 cast from the same propellant batch are to be tested under cyclic thermal conditions during the next reporting period. The objectives of these further experiments will be to investigate variation in thermal failure behavior under cyclic conditions, using the rapid cooling data included herein as a standard of comparison.

Analytical and experimental data for the entire set of analogue motors will be presented in the next monthly progress report.

C. Subcontract Effort

A final technical report of analytical studies on grain thermal analysis is currently being completed at Purdue University.

D. Future Program

Effort during the remaining two months of the program will be directed at completion of IBM 7090 thermal stress calculations, completion of experiments with analogue motors, and completion of the final technical report.

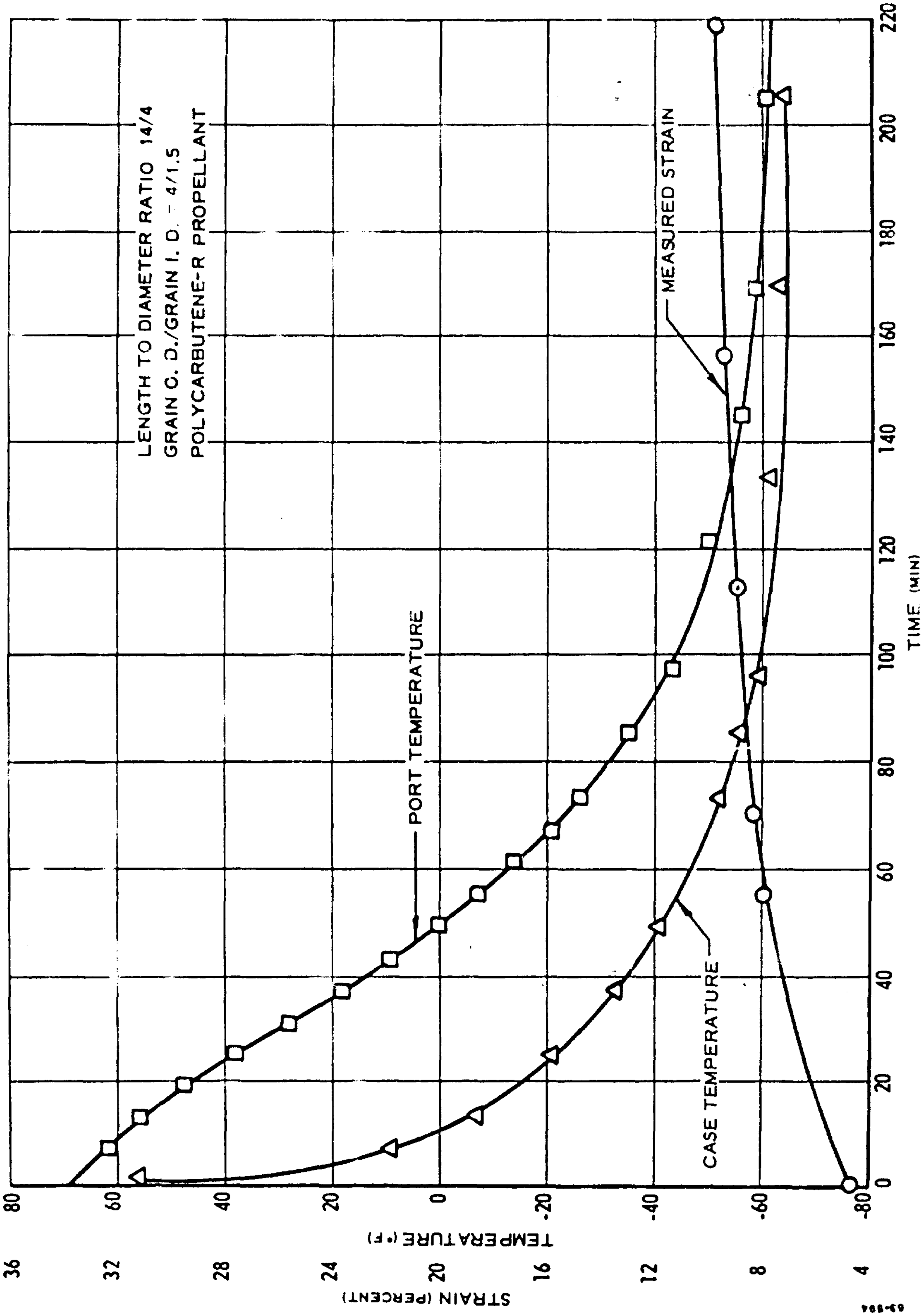

Figure 6 Analogue Motor Test Data Motor No. 1

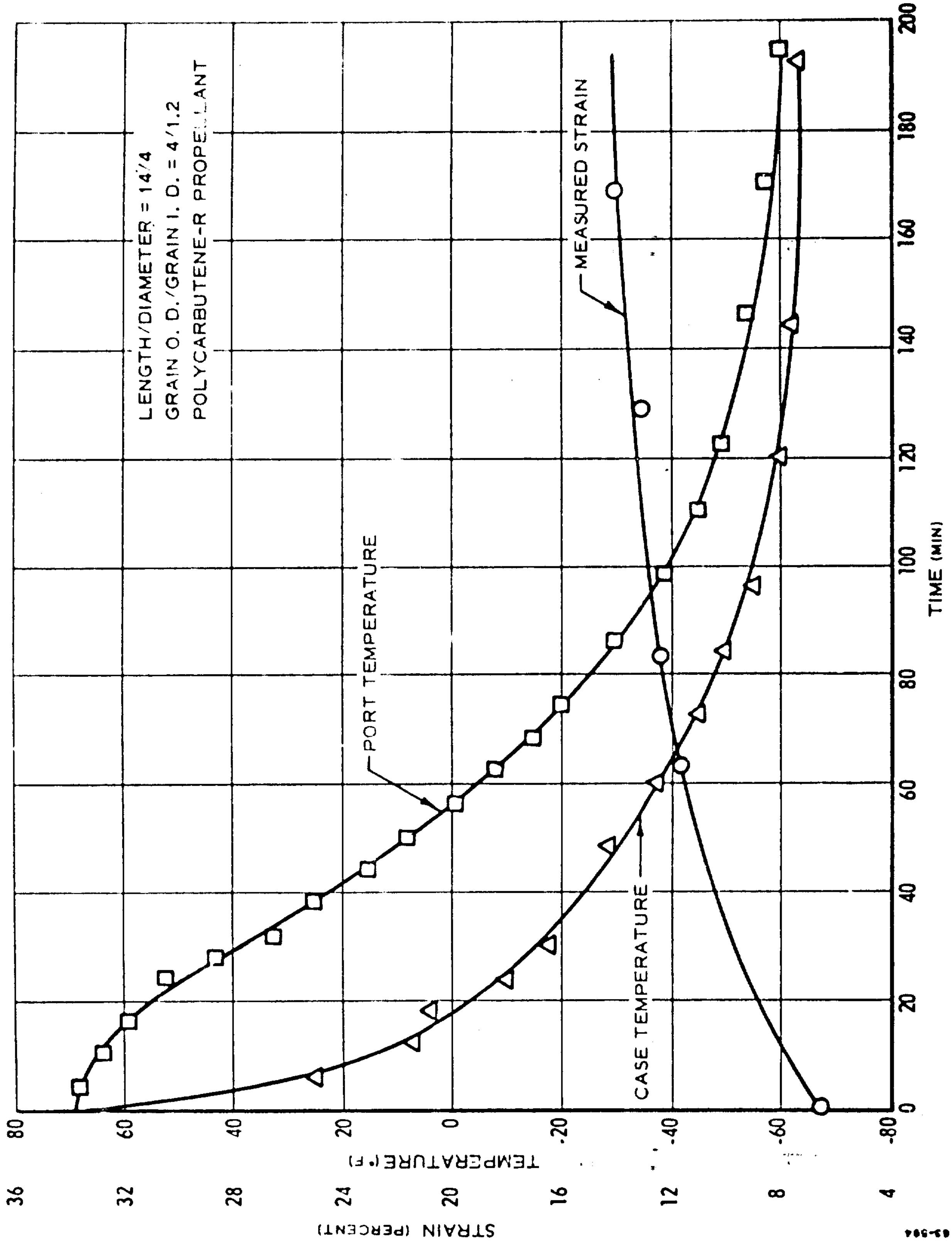

Figure 7 Analogue Motor Test Data Motor No. 2

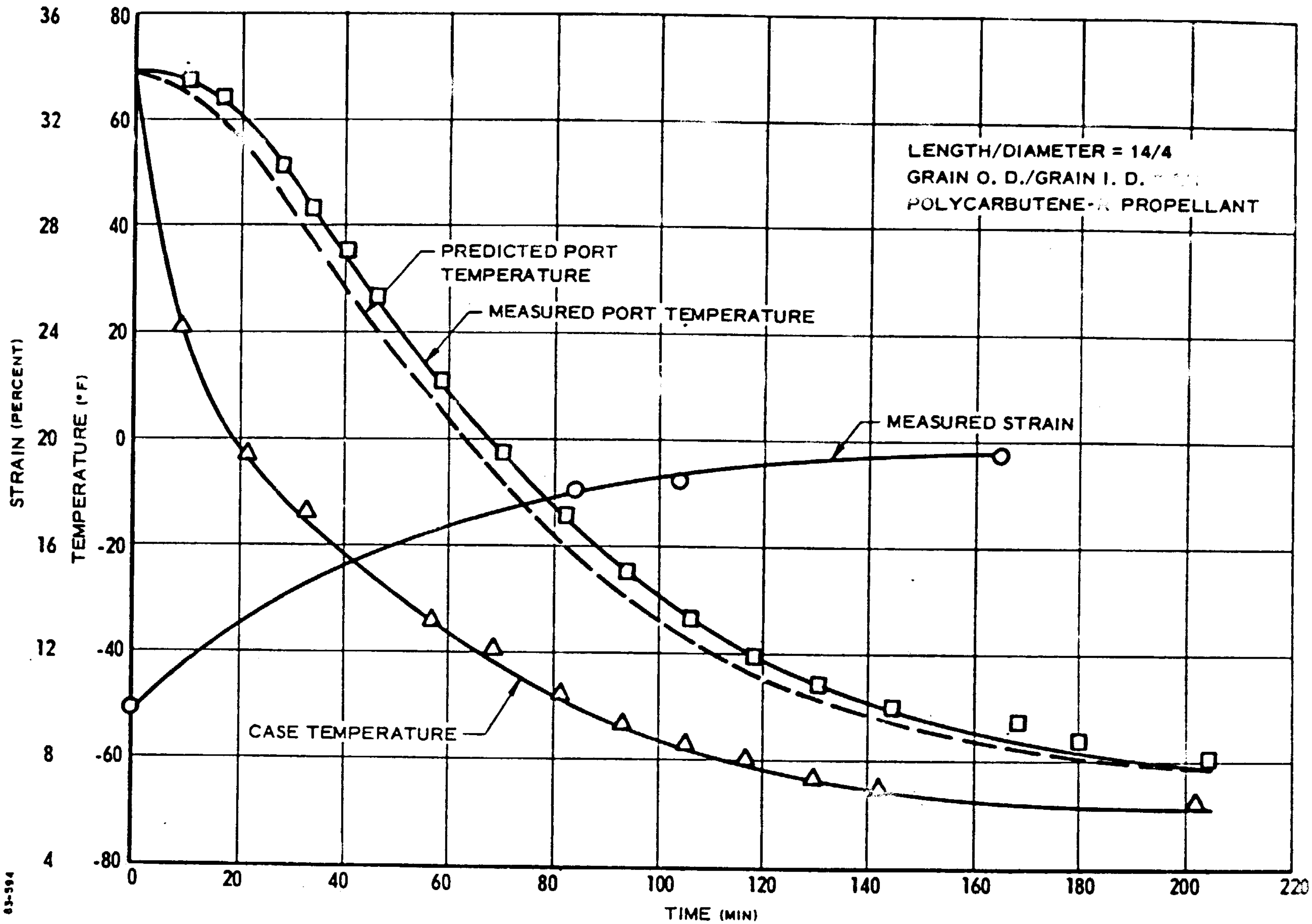

Figure 8 Analogue Mot

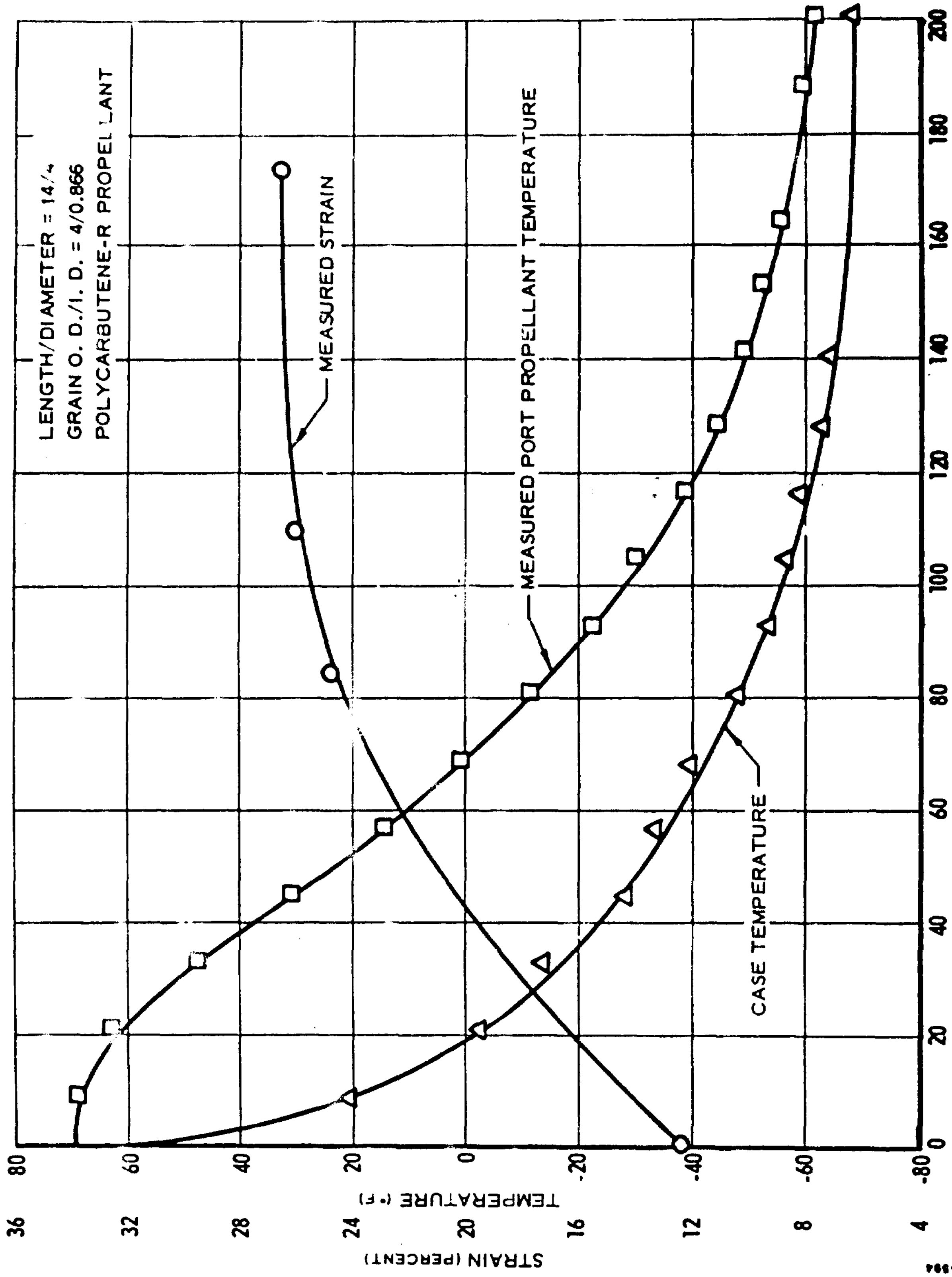

Figure 9 Analogue Motor Test Data Motor No. 4

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1. Lockheed Propulsion Company, 578-P-10, Thermal Grain Structural Analysis, 1 September through 30 September 1962.

2. Lockheed Propulsion Company, 578-TN-3, Thermal Grain Structural Analysis, 1 June through 31 August 1962.

3. Lockheed Propulsion Company, 578-TN-2, Thermal Grain Structural Analysis, 1 March through 31 May 1962.

4. Lockheed Propulsion Company, 578-TN-1, Thermal Grain Structural Analysis, 3 December 1961 through 28 February 1962.

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Lockheed Propulsion Company, P.O. Box 111, Redlands, California
"THERMAL GRAIN STRUCTURAL ANALYSIS," 10 January 1963, Program Progress Report No. 13, Period Covered: 1 December through 31 December 1962. [13] p. 9 figures. Contract No. AF05(611)-8013

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