RECUPERATOR DEVELOPMENT PROGRAM
SOLAR BRAYTON CYCLE SYSTEM

PROGRESS REPORT
NOVEMBER 1964 TO JANUARY 1965

INTRODUCTION

This report describes the work accomplished by the AiResearch Manufacturing Division of The Garrett Corporation, Los Angeles, California, during the above reporting period under National Aeronautics and Space Administration Contract NAS3-2793. This contract is for the development of a recuperator to be utilized in a closed Brayton Cycle space power system which will use solar energy as the heat source and argon as the working fluid.

A letter directed to Kenneth Parker from John Toma, and received January 13, 1965, requested recuperator weights for pressure drops ranging from 1.5 to 3 percent and for effectivenesses from 88 to 91 percent. The work accomplished during this reporting period was to furnish the required information.

The following curves represent the results of a detailed parametric analysis for the flight weight recuperator. Variables were pressure drop ($\Delta P/P$ from 1.5 to 3 percent) and effectiveness (88 to 92 percent). The analysis considered axial conduction. It is expected that flow distribution problems may contribute to lower than predicted performance; any change in recuperator performance due to flow distribution was not included in the analysis.

Items held constant during the analysis are listed below:

a) Hastelloy "C" tube plates, 0.005 inches thick
b) Hollow stainless steel header bars
c) Stainless steel side plates and manifolds
d) Nickel fins, 0.004 inch thick
e) Plane rectangular fins in the high pressure triangular section only (none on the low pressure side in the triangular section).

Figure 1 is a sketch of a recuperator cross-section. There are three distinct areas for design analysis indicated on this figure: (1) the core--plate fin matrix where all heat rejection takes place and pressure changes occur due to friction, momentum change, entrance and exit losses, (2) the triangular sections--fins on high pressure side only, pressure losses due to friction, expansion and contraction, (3) the manifolds--6 in. diameter inlet and outlet on

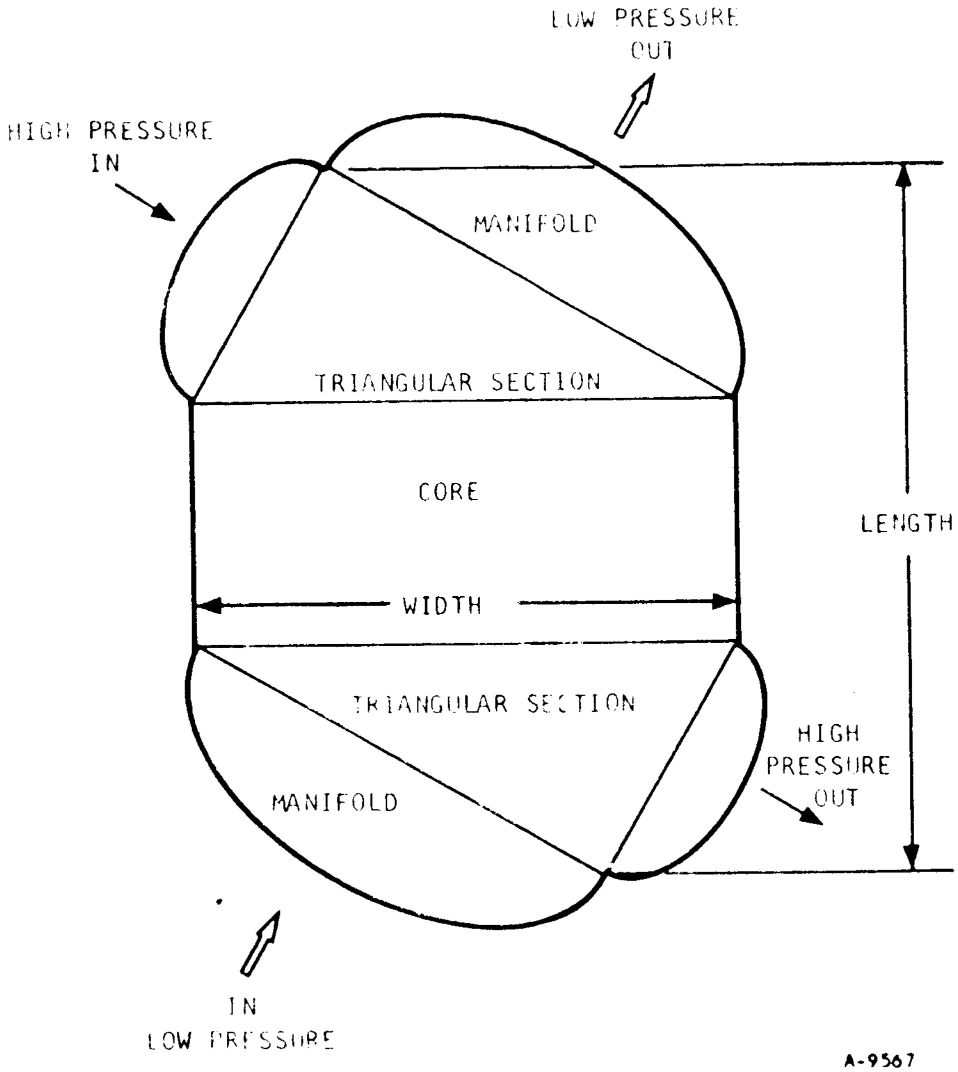

Figure 1. Recuperator Cross Section

high pressure side and 8 in. diameter inlet and outlet on low pressure side, pressure losses due to expansion and contraction.

All solutions of this parametric study are similar in shape to the sketch. As the total allowable pressure drop or the desired effectiveness changes, the weight and size of the core, triangular sections, and manifolds changes. The length plotted on the following figure is defined on Figure 1 as the core length plus the height of the triangular sections. Not included in the plotted length is the extension of the manifolds.

The area plotted on Figure 2 is the core width times the stackup height of the recuperator. Since the face of the core is essentially square, the width or stackup height of the core is the square root of the area.

Weight plotted is the total recuperator weight. This weight may or may not increase depending on the results of the flow distribution tests. The total pressure drop plotted includes the loss in each of the three main design areas and is defined in terms of percent as follows:

$$\left(\frac{\Delta P}{P}\right)_{\text{Total}} = \left(\frac{\Delta P}{P}\right)_{\text{Hot Side}} + \left(\frac{\Delta P}{P}\right)_{\text{Cold Side}}$$

where ($\Delta P/P$) hot side is the pressure drop on the hot side divided by the inlet pressure on that side. The analysis was done minimizing ($\Delta P/P$) total, rather than minimizing the pressure drop on the hot or cold side.

In order to present the ratio between core pressure losses and the total recuperator losses, the three curves in Figure 3 were plotted. It was found that pressure drop ratios were almost independent of effectiveness. The curves on Figure 3 are accurate to within four percent over the range of effectivenesses and pressure drops covered in this study. Using Figure 2, a recuperator solution may be selected (weight, area, and length at a given pressure drop and effectiveness); by using Figure 3, the following items can be determined:

a) Total hot side pressure drop

b) Total core pressure drop

c) Hot and cold side core pressure drop

d) Hot, cold, and total manifold losses.

By means of simple arithmetic, the hot and cold pressure drops in each of the three main design areas may be determined.

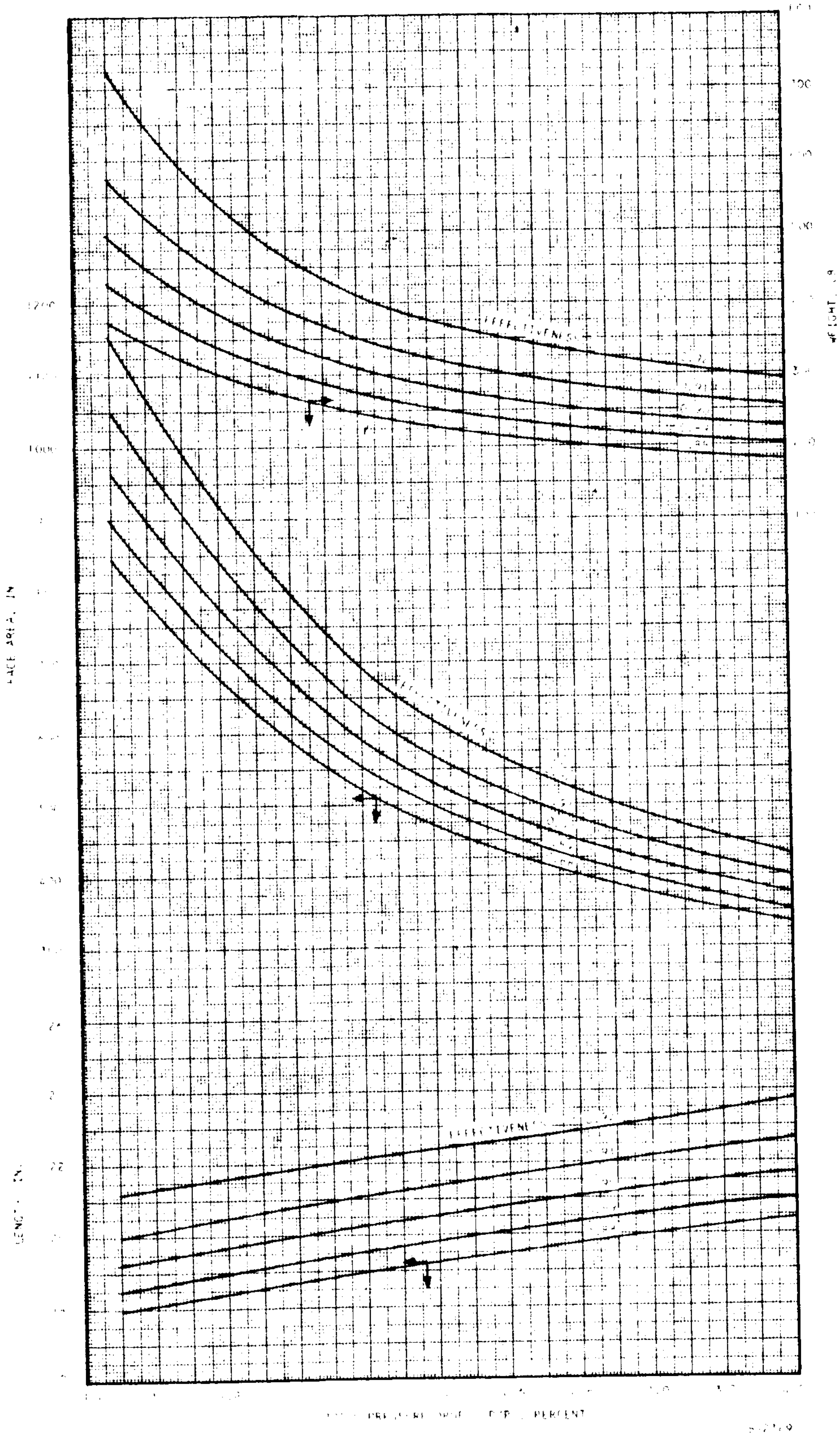

Figure 2. Effect of Total Pressure Drop and Effectiveness on Heat Exchanger Dimensions

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THE GARRETT CORPORATION
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PREPARED BY L. E. Evans

EDITED BY E. F. Busch

APPROVED BY K. O. Parker
K. O. Parker

Approved By R. D. Mueller
R. D. Mueller

REVISIONS				ADDITIONS			
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LEGEND:

1. $\left(\frac{\Delta P}{P}\right)_{HOT\ CORE}$ PERCENTAGE PRESSURE DROP ON HOT SIDE OF CORE ONLY

2. $\left(\frac{\Delta P}{P}\right)_{TOTAL\ CORE}$ $\left(\frac{\Delta P}{P}\right)_{HOT\ CORE} + \left(\frac{\Delta P}{P}\right)_{COLD\ CORE}$

   PERCENTAGE PRESSURE DROP ON HOT SIDE OF CORE PLUS COLD SIDE OF CORE

3. $\left(\frac{\Delta P}{P}\right)_{TOTAL\ HOT}$ PERCENTAGE PRESSURE DROP ON HOT SIDE INCLUDING MANIFOLDS, TRIANGULAR SECTIONS, AND CORE

4. $\left(\frac{\Delta P}{P}\right)_{TOTAL}$ $\left(\frac{\Delta P}{P}\right)_{TOTAL\ HOT} + \left(\frac{\Delta P}{P}\right)_{TOTAL\ COLD}$

   PERCENTAGE PRESSURE DROP ON HOT SIDE PLUS PERCENTAGE PRESSURE DROP ON COLD SIDE

5. $\dfrac{\left(\frac{\Delta P}{P}\right)_{HOT\ CORE}}{\left(\frac{\Delta P}{P}\right)_{TOTAL\ CORE}}$ = 0.71

6. $\left(\frac{\Delta P}{P}\right)_{HOT\ MANIFOLD}$ (8 INCH) 0.40

7. $\left(\frac{\Delta P}{P}\right)_{COLD\ MANIFOLD}$ (6 INCH) 0.36

8. $\left(\frac{\Delta P}{P}\right)_{TOTAL\ MANIFOLDS}$ (6.8 INCH) 0.76

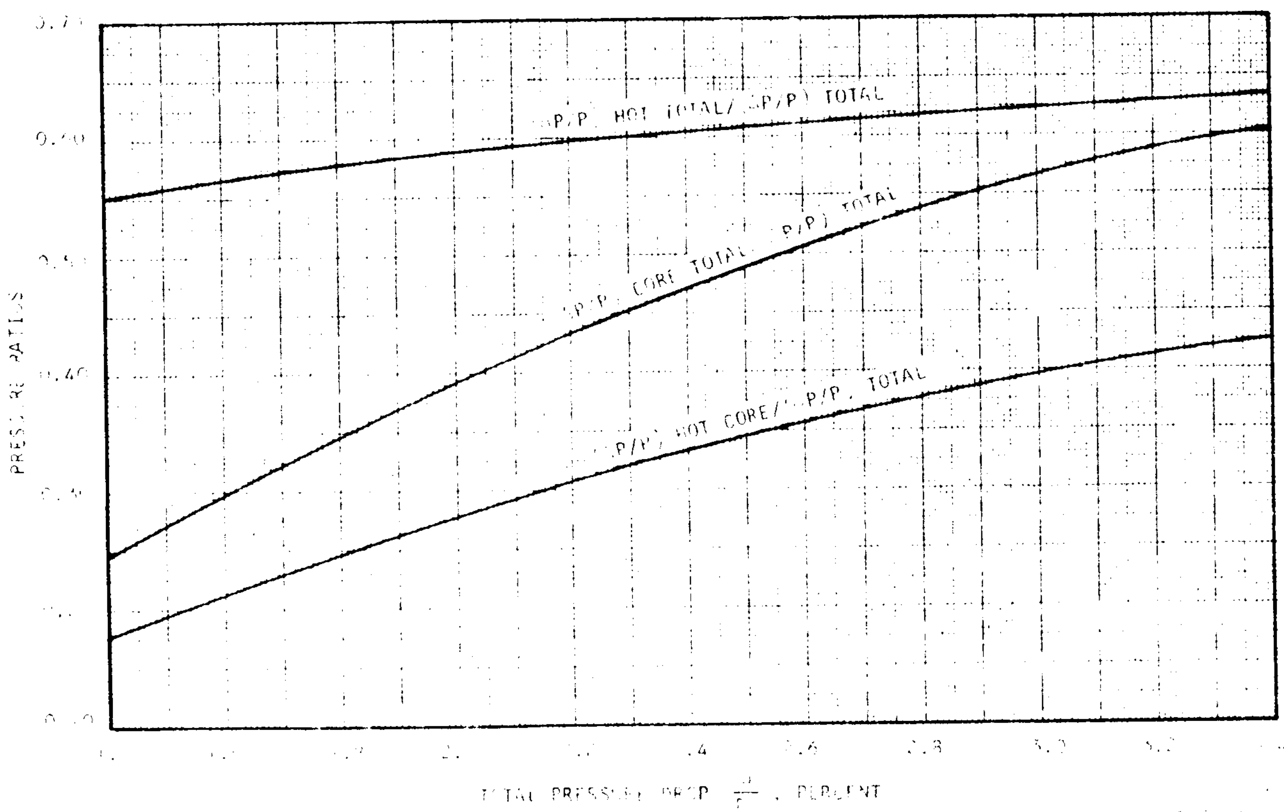


Figure 3. Pressure Drops

In the previous two progress reports, different weights were reported for the recuperator. AiResearch report L-9377, dated October 30, 1964, stated that the weight of the Hastelloy "C" unit increased from 303 to 341 pounds. This increase in weight resulted from a better estimate of axial conduction.

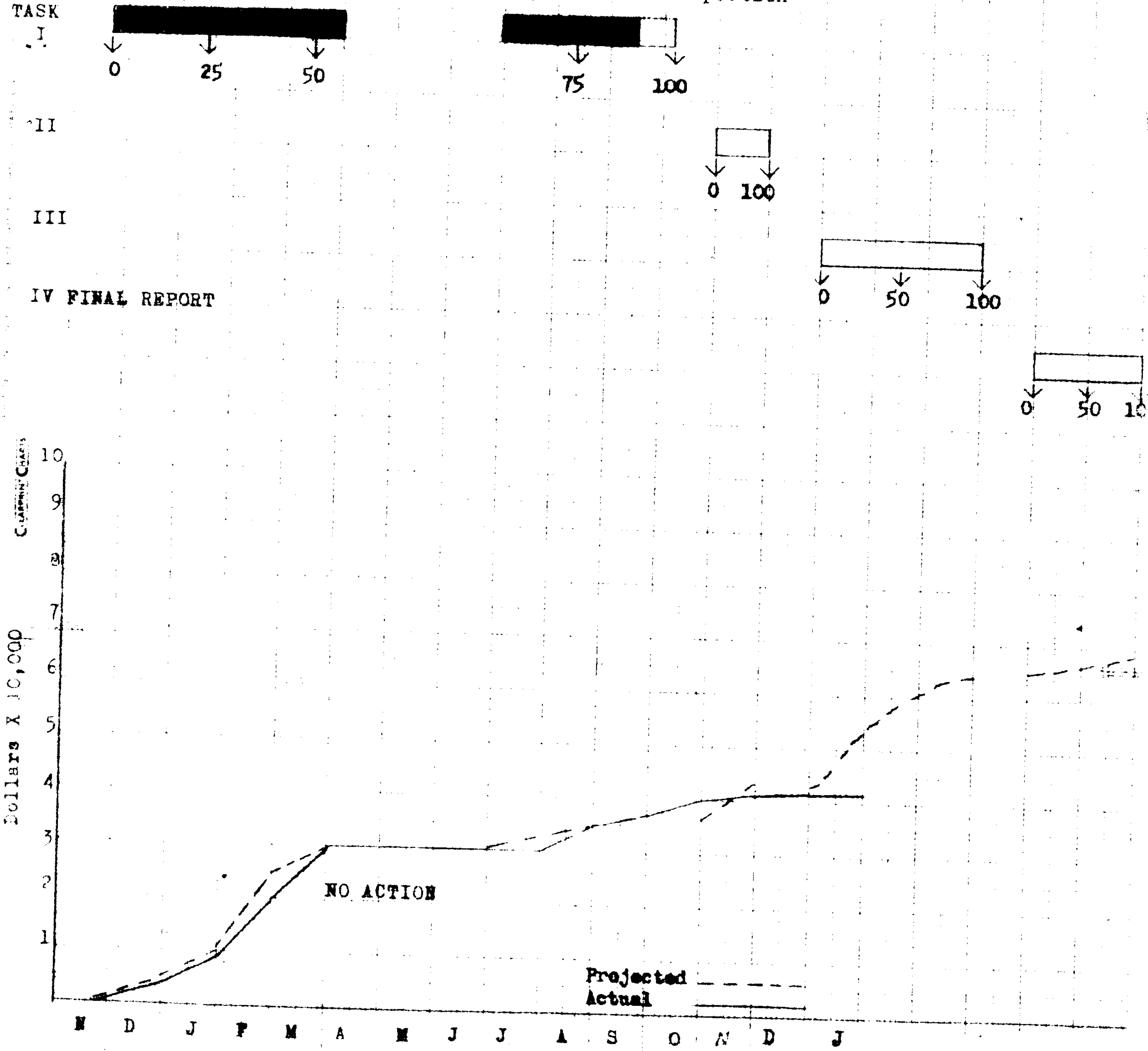
AiResearch report L-9378, dated December 1, 1964, contains a table of pressure drops and recuperator weight. These weights were obtained from computer results that listed only the pressure drop in the core. To get the total recuperator pressure drop, the total core pressure drop-total recuperator pressure drop ratio was assumed constant at a value of 0.39. This assumption was very poor as indicated by the curve on Figure 3--($\Delta P/P$) core/($\Delta P/P$) total varies considerably with total pressure drop.

COST MANAGEMENT

Figure 4 is a cost management curve and shows a comparison between the estimated and actual cost of the program to date. Also shown on the figure is the percentage of the tasks completed. Very little work has been done on this program during this reporting period pending NASA approval to proceed with the flow distribution tests.

COST MANAGEMENT REPORT

Percentage of Task Completion



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NASA-SPACE STUDIES
BRAYTON CYCLE HEAT EXCHANGER
FIGURE 4