SEMI-ANNUAL REPORT
NsG-711/44-07-004

HEAT TRANSFER ACROSS SURFACES IN CONTACT: PRACTICAL EFFECTS OF TRANSIENT TEMPERATURE AND PRESSURE ENVIRONMENTS

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NASA GRANT NsG-711/44-07-004

HEAT TRANSFER ACROSS SURFACES IN CONTACT: PRACTICAL EFFECTS OF TRANSIENT TEMPERATURE AND PRESSURE ENVIRONMENTS

Submitted by

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April 1, 1966, to October 1, 1966

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INTRODUCTION

1. During this period we continued the studies that were discussed in the previous report. In addition to these areas we made thermal conductivity measurements on some metals which were used in the contact conductance experiments.

1.1 EXPERIMENTAL -

Most of the effort in this period was concerned with obtaining data for studies with one dimensional systems. We obtained information for various combinations of length, materials, and contact conductances in which we varied the ambient environment as well as the forces holding the two cylinders together. While we are still analyzing the results and are performing more experiments we believe that the analytical studies previously reported can be used for prediction of transient effects.

1.2 THEORETICAL STUDIES -

During this period we were concerned with providing checks for the numerical program for predicting heat transfer across surfaces in contact (transient effects in two dimensions). To do this we developed a steady state solution which gave us agreement with the two dimensional program that was reported earlier. We are working now with other checks and are considering potential correlations as well as design of experiments. In many practical applications of these studies the two dimensional results may have more application than one dimensional studies. This will be described later in the report.

1.3 A POSSIBLE CONTROL APPLICATION -

The development of a passive control device in which contact conductance plays a part was discussed in the previous report. The preliminary study has been completed and the results are discussed later in this report.

1.4 METAL THERMAL CONDUCTIVITY -

In the previous report we indicated that we needed to obtain more accurate values of contact conductance coefficients by knowing more accurately the thermal conductivity of the metals which we use in our systems. We finished constructing and testing apparatus almost identical to the one described by Watson and Robinson (1). The required data were obtained.

2. ONE DIMENSIONAL TRANSIENT EXPERIMENTS

2.1 PRELIMINARY REMARKS -

At present a detailed analysis is being made of all the one dimensional experimental studies that have been made to date and the apparatus is being modified in

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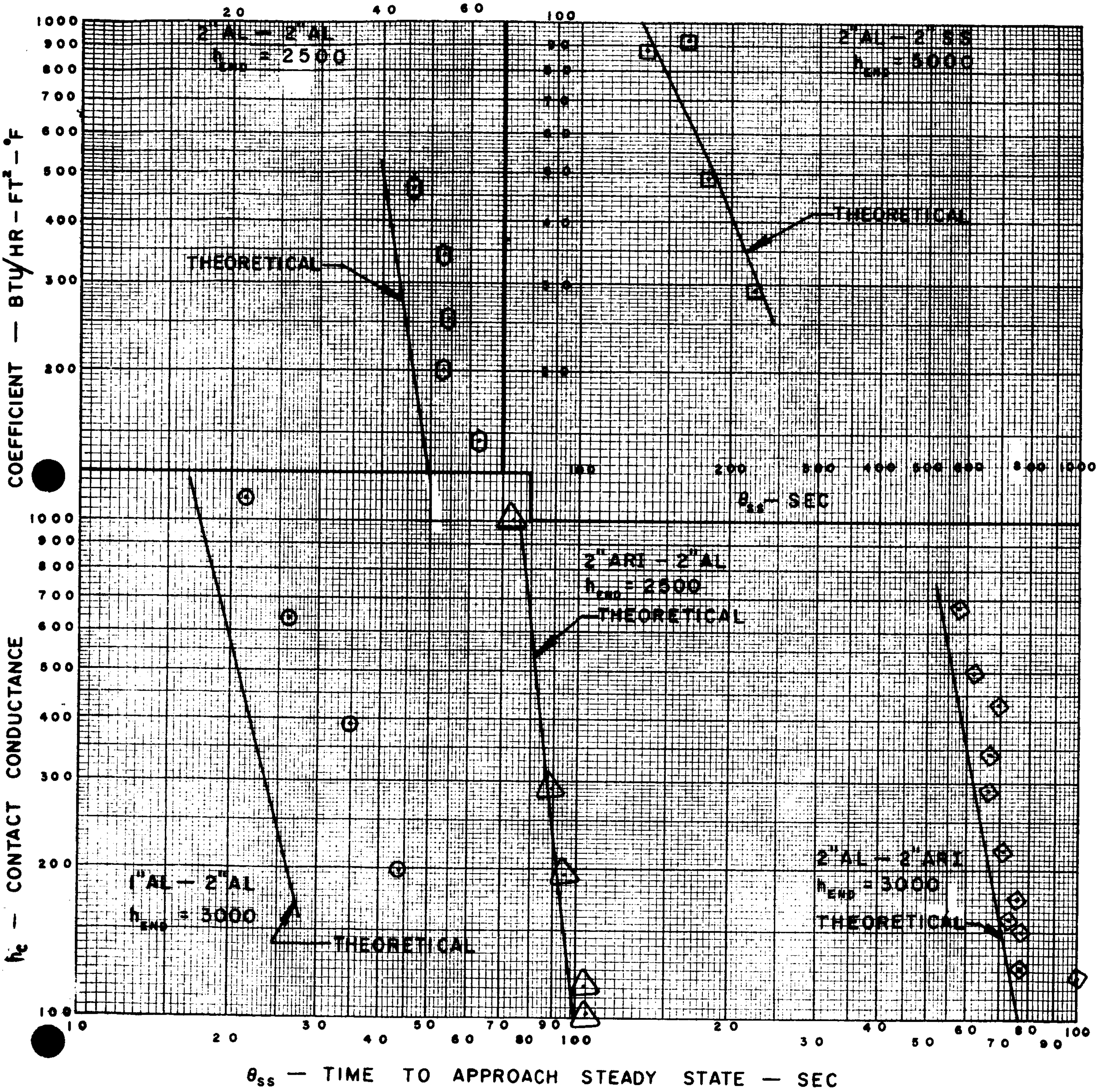
(1) T. W. Watson and H. E. Robinson, "Thermal Conductivity of Some Commercial Iron-Nickel Alloys," Journal of Heat Transfer, Nov. 1961, pp 403-408

order to prevent the numerous time consuming calibrations. We have concluded that the transient behavior of two-layer composite metals with contact resistance can be predicted from simple theoretical solutions (which we developed) to an accuracy sufficient for most engineering purposes. (2)

2.2 COMPARISON OF THEORY AND EXPERIMENT -

A detailed analysis is being made which will appear in the dissertation of Clifford J. Moore, Jr. It is expected that this dissertation will have been completed by June, 1967.

Our object is to compare how well the simple one dimensional constant property analytical and numerical solutions could predict the transient behavior of real composite systems with contact resistance at the interface. To do this, two characteristics of the system which the earlier theoretical work showed to be significant, were used in the comparison. These were (1) the time to approach steady state and (2) the contact ΔT (or contact heat flux) over-shoot phenomenon. In the earlier studies we used the 99% criterion (that is, we assumed that the system was at steady state when the temperature drop across the slowest reacting portion of the system was 99% of its steady state value). We changed that criterion to 63.2% (time to approach within one time constant) since this would reduce the effect of the experimental error. The results are shown in Fig. 1. The solid lines represent the theoretical predictions; whereas, experimental data points are plotted with symbols. It will be noticed that the comparison is better for some experiments than for others. The agreement is better for the slower reacting systems. This is believed to be true because the source temperature (copper block-steam system) dips at the first contact because it actually does have a finite capacity, or in other words, for a few seconds the source temperature is low. This means that the low over-all resistance systems (which would have a shorter time to reach the steady state) would have a greater error than systems with larger over-all resistance. A comparison of the 2-inch Armco Iron sample above a 2-inch aluminum sample as contrasted with the 2-inch aluminum over another 2-inch aluminum sample illustrates this. The Armco Iron being a poor conductor does not cause as much dip in the source temperature. The result of this argument is that the experiment and theory agreement is good. A second comparison between theory and experiment is concerned with the time required for the temperature drop across the contact (ΔT_c) to reach its peak. In Fig. 2, the comparison is made. An agreement is seen to follow the same


h_c — CONTACT CONDUCTANCE COEFFICIENT — BTU/HR - FT^2 - °F
θ_{ss} — TIME TO APPROACH STEADY STATE — SEC
θ_{ss} — SEC
2" AL — 2" AL
h_{END} = 2500
2" AL — 2" SS
h_{END} = 5000
2" ARI — 2" AL
h_{END} = 2500
1" AL — 2" AL
h_{END} = 3000
2" AL — 2" ARI
h_{END} = 3000
THEORETICAL
THEORETICAL
THEORETICAL
THEORETICAL
THEORETICAL
1000
900
800
700
600
500
400
300
200
100
10
20
30
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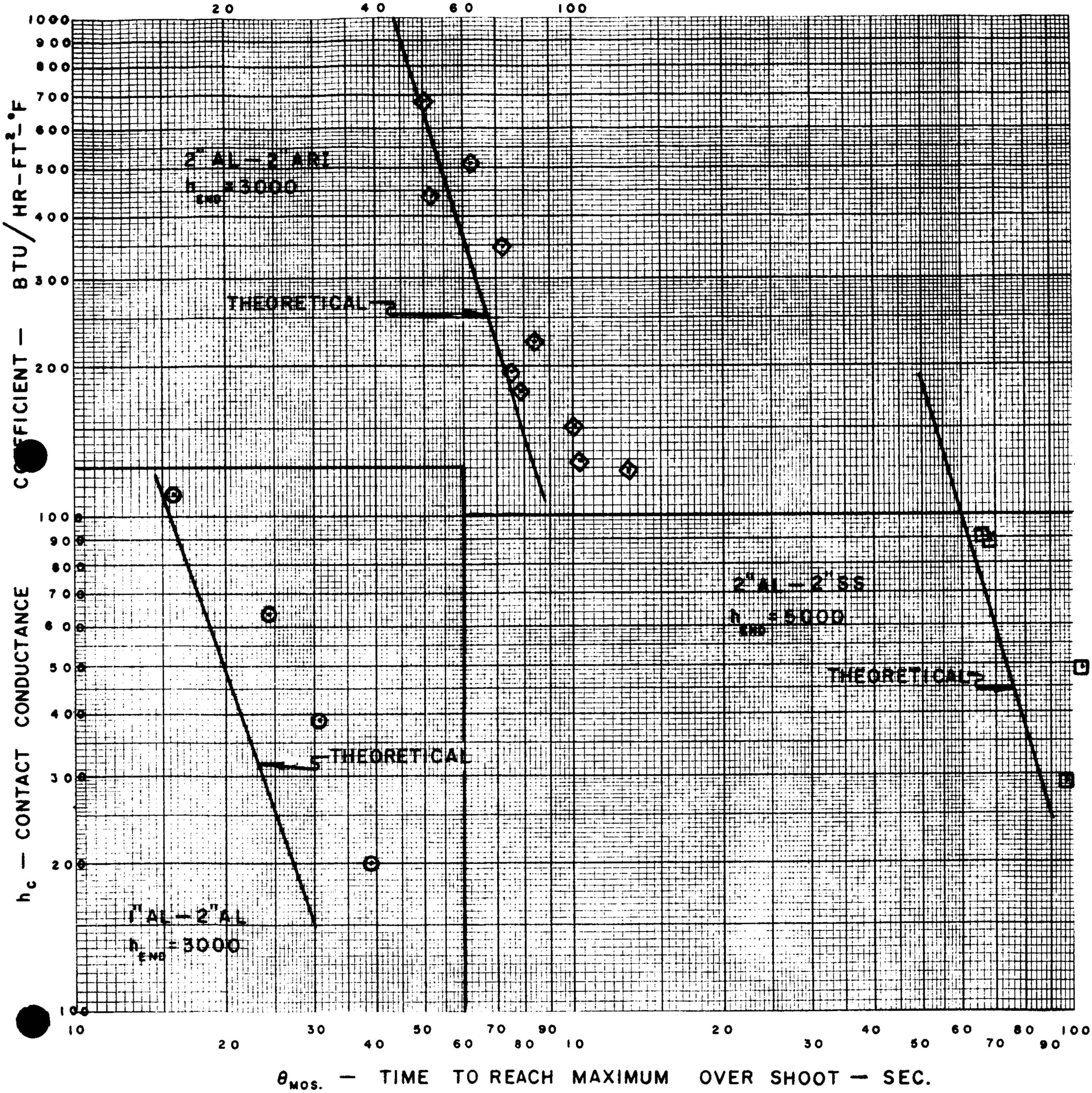
50
60
70
80
90
100
200
300
400
500
600
800
1000

FIG. I.



2" AL – 2" ARI
h_{END} = 3000
THEORETICAL
1" AL – 2" AL
h_{END} = 3000
THEORETICAL
2" AL – 2" SS
h_{END} = 5000
THEORETICAL
h_c — CONTACT CONDUCTANCE — BTU/HR-FT^2-°F
$\theta_{MOS.}$ — TIME TO REACH MAXIMUM OVER SHOOT — SEC.
1000
900
800
700
600
500
400
300
200
100
20
40
60
100
10
30
50
70
80
90

FIG. 2

pattern as above. It will be noticed that the error is such (as in the previous case) that the experimental observations appear to be somewhat slower (seconds) than the theoretical. This also seems to agree with the hypothesis that the source dips in temperature for a few seconds.

2.3 OTHER FACTORS -

The above comparison was concerned with what we had labeled phase 1 of our experiments. The other factors which are now being analysed are concerned with phases 2, 3, and 4. In phase 1, the system originally at room temperature in a vacuum was suddenly exposed at one end to a higher temperature. When steady state was achieved, phase 2 began by a sudden increase of the force which held the two cylinders together. This changed the contact resistance and a new steady state distribution was ultimately achieved. In phase 3, the force was relaxed to the original condition so that the time-temperature distribution could be observed again. In phase 4, the system at the original contact pressure (in a vacuum environment) was exposed to air which was allowed to enter the previously evacuated bell jar. Phases 5 and 6 included application of a larger contact force to the system (with air in the interstices) followed by a relaxing of this pressure to the original condition.

2.4 FUTURE ACTIVITIES -

For this next period we shall continue to make measurements concentrating our efforts on phases 2 through 6 (mentioned above) and to examine longer period exposures to transient cycling.

3. TWO DIMENSIONAL HEAT TRANSFER ACROSS SURFACES IN CONTACT: A THEORETICAL STUDY

3.1 BACKGROUND -

In this phase of our study we are concerned with the behavior of many systems in contact with a common sink. In the previous report we showed the results of a two dimensional study. In this system we would like to determine the area on the sink outside of the heat source which was affected by the higher temperature block in contact with it. During this period we have been concerned with proof of our method and extending the model to systems in which convection and radiation from the surfaces would be allowed.

3.2 THE CHECKS -

In the previous report our model consisted of a block in contact with a sink. The sides of the block and the surfaces of the sink not in contact with the block were considered to be insulated. The solution of the appropriate differential equation by the explicit finite difference approach resulted in the information which was presented. In this period we developed a two dimensional steady state solution of the same problem and showed that as time increased in our transient solution the temperature distribution matched the steady state solution. We have also decreased the time increment used in the solution and found that the maximum time increments we had chosen previously also resulted in the same temperature distribution.

During the next report period we will adjust the dimensions of our two dimensional model to see if we can compare our model with the one dimensional case which has been successful. With the assurance of these checks (checks which should be included with the final presentation of any numerical analysis) we can proceed with selected production runs to provide a guide for placing several sources of heat on single reservoirs.

4. A PASSIVE THERMAL CONTROL DEVICE

In the previous report we discussed our experience with a varying contact surface device which could provide a passive thermal control of systems. We have done as much as we can and still stay within the framework of this research problem. The results are presented in Appendix I (written by Frank A. Fitz).

We conclude that (1) a passive control device as we visualized which is based on a changing contact surface does indeed work, (2) the control portion of the system is simple and would be inexpensive to fabricate.

5. METAL THERMAL CONDUCTIVITY

In order to obtain more accurate values for contact conductance coefficients we constructed an apparatus which was almost identical to the one described by Watson and Robinson (1). This device has been built, checked, and data obtained for the materials that have been used in the one dimensional contact conductance studies. In Appendix 2 is a copy of the thesis by David R. Williams which describes fully our activities with this method for determining thermal conductivity.

6. PERSONNEL

Harold A. Blum, Principal Investigator, Professor of Mechanical Engineering.

Clifford J. Moore, Jr., completing his dissertation on the experimental transient studies; presently Assistant Professor at North Carolina State University, Raleigh, North Carolina.

David R. Williams, measured thermal conductivity of metals used in this study; completed his master's degree.

Lenox Carruth has completed his comprehensives and will work on his dissertation in some aspect of this research.

John Haessly is working on measurements of some metal thermal conductivities; studying for his master's degree.

Thomas Ashley, working on transient effect; working on his master's degree.

J. P. Kenny, Jr., doing theoretical studies in connection with two dimensional work; working on his master's degree.