FINAL REPORT

on

MODIFICATIONS TO THE RAPID MELT/RAPID QUENCH AND TRANSPARENT POLYMER VIDEO FURNACES FOR THE KC-135

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Section 1.0: Introduction

In early 1988 two furnace systems developed by Wyle Laboratories were delivered to the Marshall Space Flight Center and subsequently to the SSL Solidification Physics Lab. It was soon determined that a number of modifications and improvements were required prior to any attempt of flight operations aboard NASA's KC-135. Initially it was thought that only minor hardware modifications would be required. Once work began however it was determined that major changes were needed for both furnaces to operate according to the scientific investigators' experiment parameters. These two systems were the Transparent Polymer and the Rapid Melt/Rapid Quench Furnace (henceforth TPF and RMRQ).

This document provides a summary of tasks performed to both furnace systems. It includes what the initial inherent problems were, what was required to solve the problems, and possible future enhancements. It has been determined that such enhancements will be required for both furnaces to perform to their optimal level. During the past year the services provided fall into seven general categories. They include:

1. Hardware modifications
2. Software modifications
3. Safety DataPackage documentation in accordance with MSFC and JSC requirements.
4. Ground based testing
5. Transportation to and from Ellington Air Field
6. Operation of hardware during KC-135 flights
7. Post flight data processing

The majority of the work performed was to the RMRQ furnace as it required the most hardware oriented modifications.

Section 2.0
Tasks Performed to the RMRQ Furnace System

Originally the RMRQ furnace was designed to be capable of two distinct functions within one package. This included the ability to melt and resolidify a metal alloy sample within one low g period and also serve as a directional solidification furnace when desired. When work first began by UAH on this system it was soon determined that the directional solidification capability could never be successfully used aboard the KC-135. This was due to the inherent structural design flaw of the translation system. As the aircraft would enter and exit low g maneuvers the changing g levels would cause flexing of the translation ball/screw drive shaft and therefore cause a change in the translation rate. This condition would be considered intolerable for directional solidification and thus the results of the sample processing non-productive. With this in mind the decision was made to remove all of the now unnecessary hardware and thus dedicate the furnace to only a rapid melt/rapid quench capability.

During a preliminary safety review conducted on October 3rd, 1988 a number of safety issues and other problems were raised. The following is a description of the issues, problems and changes.

Section 2.1: New Furnace Containment Housing

The first modification required involved the complete redesign and fabrication of a furnace containment housing. The existing unit supplied by Wyle Laboratory was essentially a bell jar with two port holes located at the base. With the bell jar in place sample change-out was determined to be too difficult and a possible safety hazard. Figure 1 displays the old bell jar configuration, while Figure 2 shows the new housing in place around the furnace. Note the use of two large Plexiglas doors to allow access to the entire furnace assembly. This access to the top of the furnace as well as the bottom was mandatory. An additional shield around the furnace assembly was also fabricated for in-flight operations. It is a stainless steel ring which acts a hand rail around the circumference of the furnace. This ring will also assist during loading and unloading operations. Foam padding is added for additional safety during the flight.

Section 2.2: Addition of Battery Backup System

Probably one of the greatest oversights concerned the lack of a battery backup or uninterruptable power supply (UPS) for the computer and servo motor control circuits. A well known fact is that power "glitches" and failures aboard the KC-135 are inevitable and sometimes frequent. Under the following conditions a severe safety hazard was determined to exist should a power failure occur. During the procedure to change out a sample the furnace canister needs to be raised to the top. Should a power failure or intermittent occur it was discovered that the furnace canister would free fall at a rate sufficient

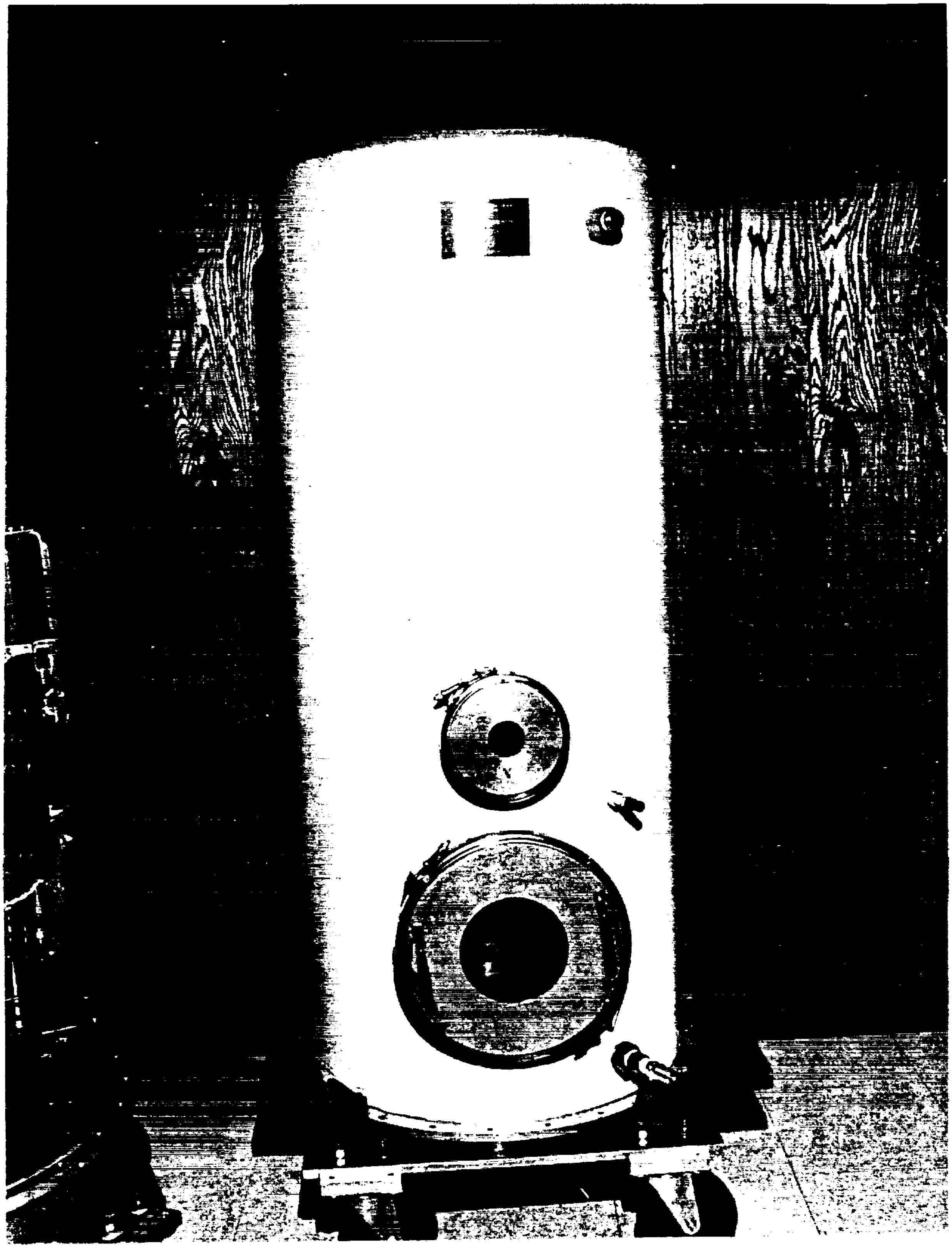

Figure 1: Old bell jar containment housing for the RMRQ

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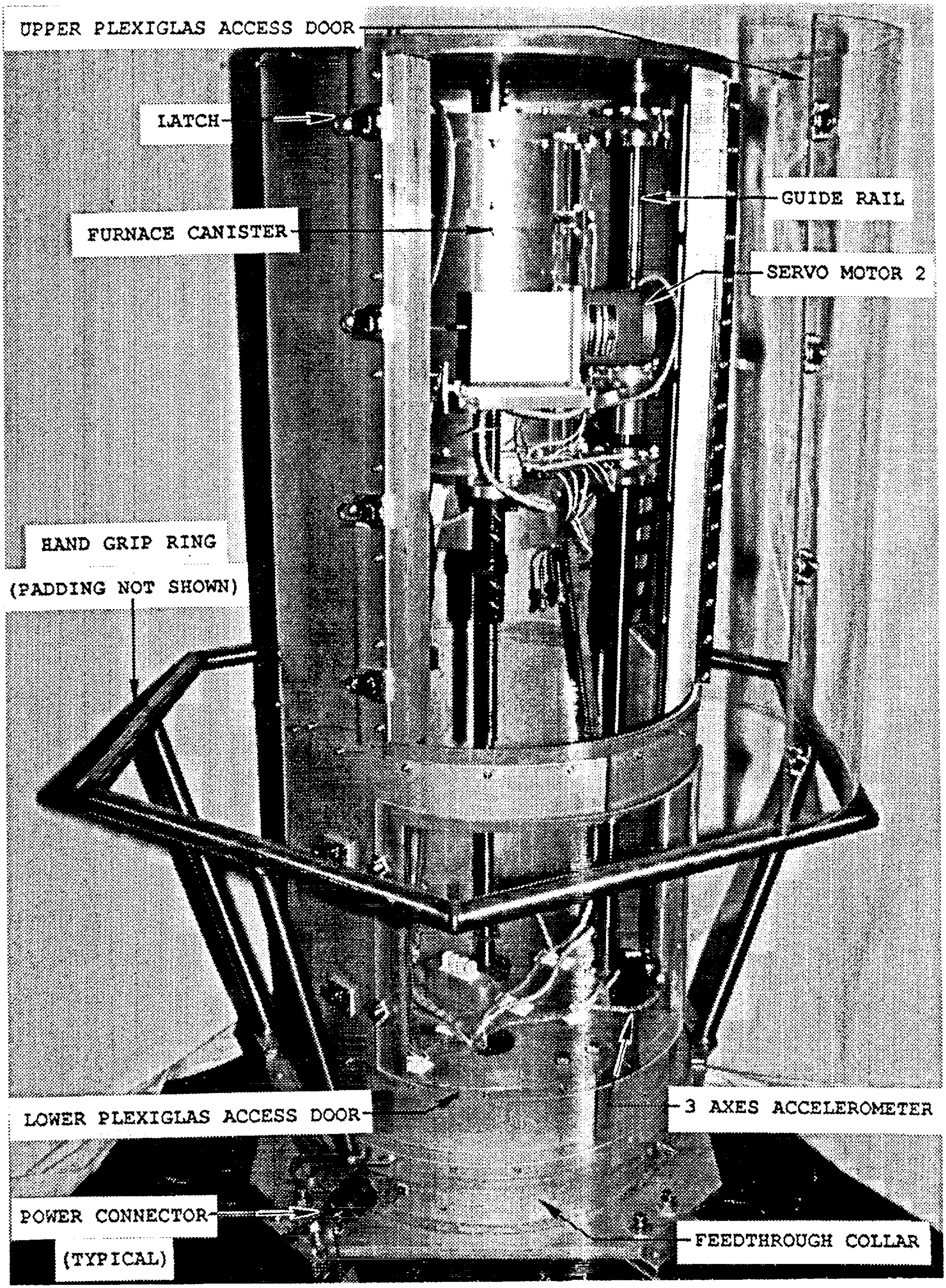

Figure 2: New RMRQ furnace containment housing with doors

enough to cause a possible injury to the operator. The injury could include severe burns, lacerations and under the proper conditions bone fractures. With this in mind a battery backup unit was installed to maintain power to both the computer and the servo motor circuits during a power problem. As an additional safety backup, a special clamp mechanism was added to the furnace translation system. With the furnace raised to the top this clamp is engaged during any sample change out procedure and prevents any possible slipping or free falling of the furnace canister. In order to manually engage the clamp, access to the top of the furnace assembly was required and thus the need for the upper door on the new containment housing.

Section 2.3: Modifications to Cooling Pallet

The next safety concern dealt with the cooling pallet. This was the separate package which provided a mounting base for the rapid water quench, furnace cooling system and the helium purge gas supply system. The safety problem was all of the sharp objects and protrusions. Since there was no protective shielding in place an in-flight injury potential existed. To counter the problem an aluminum housing was built to cover the pallet. Additional foam padding could then be easily added if required. Figure 3 exhibits the cover housing in place on the cooling pallet.

Other modifications to the cooling pallet included a complete removal of the furnace cooling and helium purge systems. Since the directional solidification function of the RMRQ was no longer needed the cooling system for the copper quench block

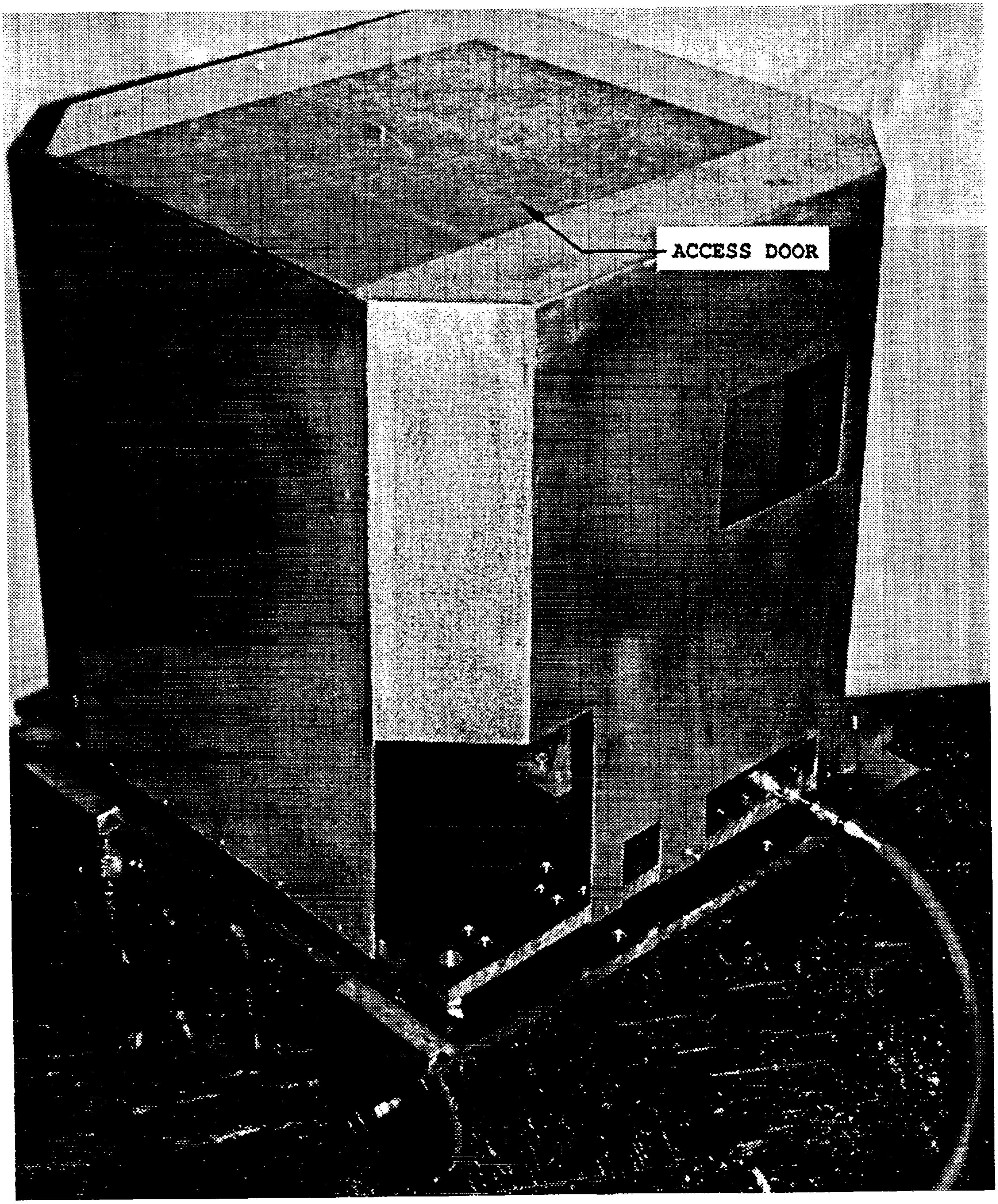

Figure 3: RMRQ cooling pallet housing

was removed. These parts would later be used for the fabrication of a cooling system for the TPF video camera as explained later. The helium purge system was removed since it was determined that the small lecture bottle size supply tank would be inadequate. A lecture bottle typically contains only 2 cubic feet of helium when fully pressurized to 1800 psig. With the flow rates required to effectively purge the sample crucible for time periods of up to 3 hours the lecture bottle supply would fall way short. It was therefore decided to remove this system as well and utilize a larger tank (K bottle size). This tank would be supplied by JSC and secured inside the aircraft using their tank rack mount. In using this size of tank a more complete purge of oxygen is guaranteed since a higher flow rate of helium is now permissible. Removing both these systems has also eliminated the safety certification task of two pressure systems.

Section 2.4: Modifications to Quenching System

A major modification to the excess water recovery system was also a prerequisite to performing a rapid water quench while either on the ground or aboard the aircraft. The initial design failed to recover most if any of the water sprayed onto the crucible containing the sample. During a 10 second water quench test period approximately 200 ml leaked from the spray chamber onto the floor of the furnace assembly. This was due to excessive plumbing and valving to control the over board vacuum flow rate and undersized vacuum tubing. Also the ports leading from the furnace water spray block were too small and thus restricted the flow rate as well. Modifications performed were based on experience gained from the rapid water quench system presently used on the KC-135 ADSF system. Modifications included changing the port configuration, enlarging the vacuum tubing, replacing the existing control valve with a proper vacuum valve, and increasing the vacuum level within the water recovery area of the water spray chamber. This was accomplished by installing baffles causing a restriction of air flow into the top and bottom of the spray chamber. Ground based processing of samples using a wet/dry vacuum cleaner as a source of vacuum has confirmed the problem to be solved.

Section 2.5: Safety Document Preparation

Before any new item of hardware can be flown aboard the KC-135 a proper safety assessment must be prepared. In July of this year the "Test Equipment Data Package for the Rapid Melt/Rapid Quench Furnace" was submitted to the MSFC Systems Safety Engineering Division for approval. In a letter dated September 13, approval was granted by D. B. Channell, Chief of MSFC SSED. The document was then forwarded to JSC Safety and accepted.

Section 2.6: Ground Based Testing

While all of the previous modifications corrected a number of safety problems there still existed a major problem with the thermal characteristics of the furnace. As ground based testing progressed it was determined that the furnace failed to meet any of the requirements for processing a sample in one low g period. The steps taken to correct the problem were as follows.

The first step taken was to define what thermal parameters would be required for processing a sample. The first user of the furnace has been identified as Dr. Donald E. Morel of Applied Research Laboratory, Inc., in conjunction with Dr. D. Stefansecu of the University of Alabama and Dr. P. A. Curreri of MSFC-SSL. Dr. Morel has two metal/ceramic composite systems for study using the RMRQ. They include a low melting monotectic (6.1 wt% Ni) and a high temperature intermetallic compound Ni_3Al (Ni-13.3 wt% Al). The ceramics to be utilized for the reinforcement include silicon carbide, aluminum oxide, and calcia-stabilized zirconia. According to his requirements the sample would be heated to just below the melting point using the preheat zone of the RMRQ. These temperatures would be 600° and 1300° C respectively. Upon entering a low g period the sample would be super heated to well above the melting point for 15 seconds and then rapid quenched with water. With these experiment parameters in mind a series of thermal profiling tests were conducted on the RMRQ. Data was collected either by hand or by the RMRQ computer, converted into a SYMPHONY spreadsheet format and then plotted.

Section 2.6.1: Thermal Profiling of RMRQ Furnace

Three different sets of furnace parameters were set up to identify the baseline thermal profile conditions of the RMRQ. These three sets were as follows:

Set Number	Preheat Temperature	Rapid Melt Temperature
1	400° C	1100° C
2	600° C	1300° C
3	600° C	1500° C

These parameters were based on the conditions necessary for the processing of aluminum composite alloys from Dr. Morel.

Referring to Figure 4, the results of the thermal profiles are given. A scale cross section of the furnace canister has been overlapped to provide reference for the temperatures. During these runs the small heater core located between the water spray block and the rapid melt core was not used. This was due to failure of one control thermocouple and excessive noise from the other. Thermal data was collected by passing a type S thermocouple down through the center of the furnace canister at one centimeter increments. During each increment a time period of 30 seconds was allowed for thermal equilibrium before the temperature was recorded. The thermocouple atmosphere was ambient air.

In studying the thermal plots it was clear that the preheat zone fell short of being isothermal. This was due to the lack of either a booster heater located at the top of the preheat zone or a loading of heater core windings at each end of the preheat core. Reviewing the Wyle designs of the of the heater core indicated even spacing of the heater windings throughout the length of the heater core. If the length of an aluminum alloy sample located within the center of preheat core is three centimeters then the top of the sample would be approximately 100^{o} C hotter than the bottom. Since the purpose of the preheat core is to hold the entire sample temperature just below the melting point this thermal characteristic was determined to be undesirable.

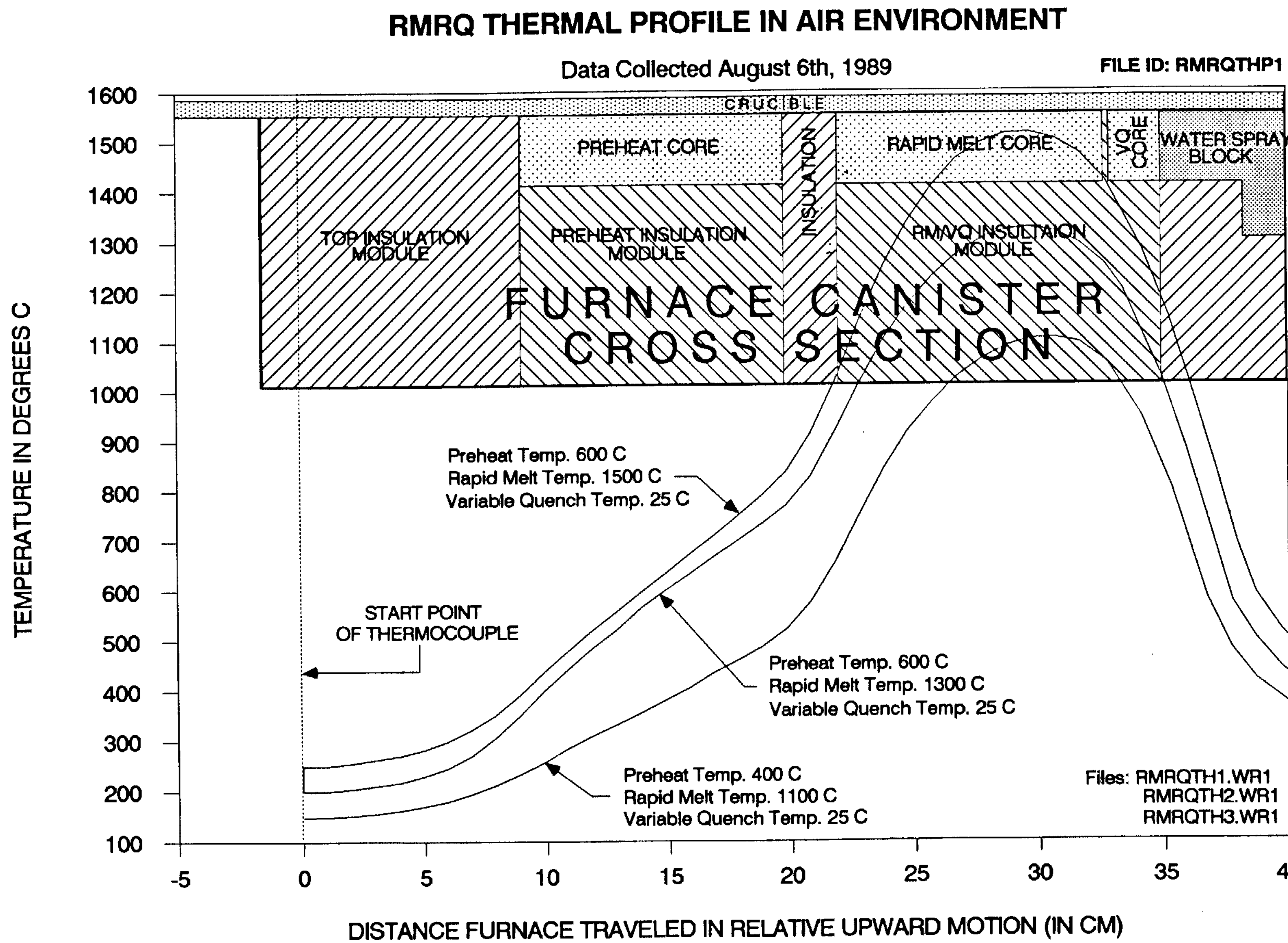

Figure 4: RMRQ thermal profile - old heater configuration

Section 2.6.2: First Ground Based Runs with Pure Aluminum

In the next step a pure aluminum sample was processed using a preheat zone temperature of 500^{o} C and a rapid melt zone temperature of 1400^{o} C. The sample temperature was monitored by a type B thermocouple and the signal fed into the data acquisition system of the RMRQ. The results of the data are given in Figure 5. There are two main points to note: (1) the sample temperature while within the preheat zone was 709^{o} C even though the preheat zone setpoint was 500^{o} C, and (2) during a 15 second dwell period in the rapid melt zone the sample temperature increased only 187^{o} degrees. These two facts indicated that the RMRQ as it existed would not be capable of achieving the desired results.

A second ground based run was performed using slightly different temperature conditions. Referring to Figure 6 the preheat zone temperature was set to 25^{o} C - essentially off and the rapid melt zone temperature was set to 1500^{o} C. In this case the results were better in that the preheat zone remained below the melting point of the sample. Even with the setpoint at 25^{o} C the sample temperature still reached 611^{o} C. This was due to the heat flux from the rapid melt zone. During the 15 second rapid melt dwell period the sample temperature reached 861^{o} C, an increase of 250^{o} C and 63 degrees more than in the previous run. In as far as processing the metal/ceramic composite alloys for Dr. Morel, this run indicated that his lower temperature system could be successfully processed during a KC-135 flight. However as for other types of alloy systems the current conditions would

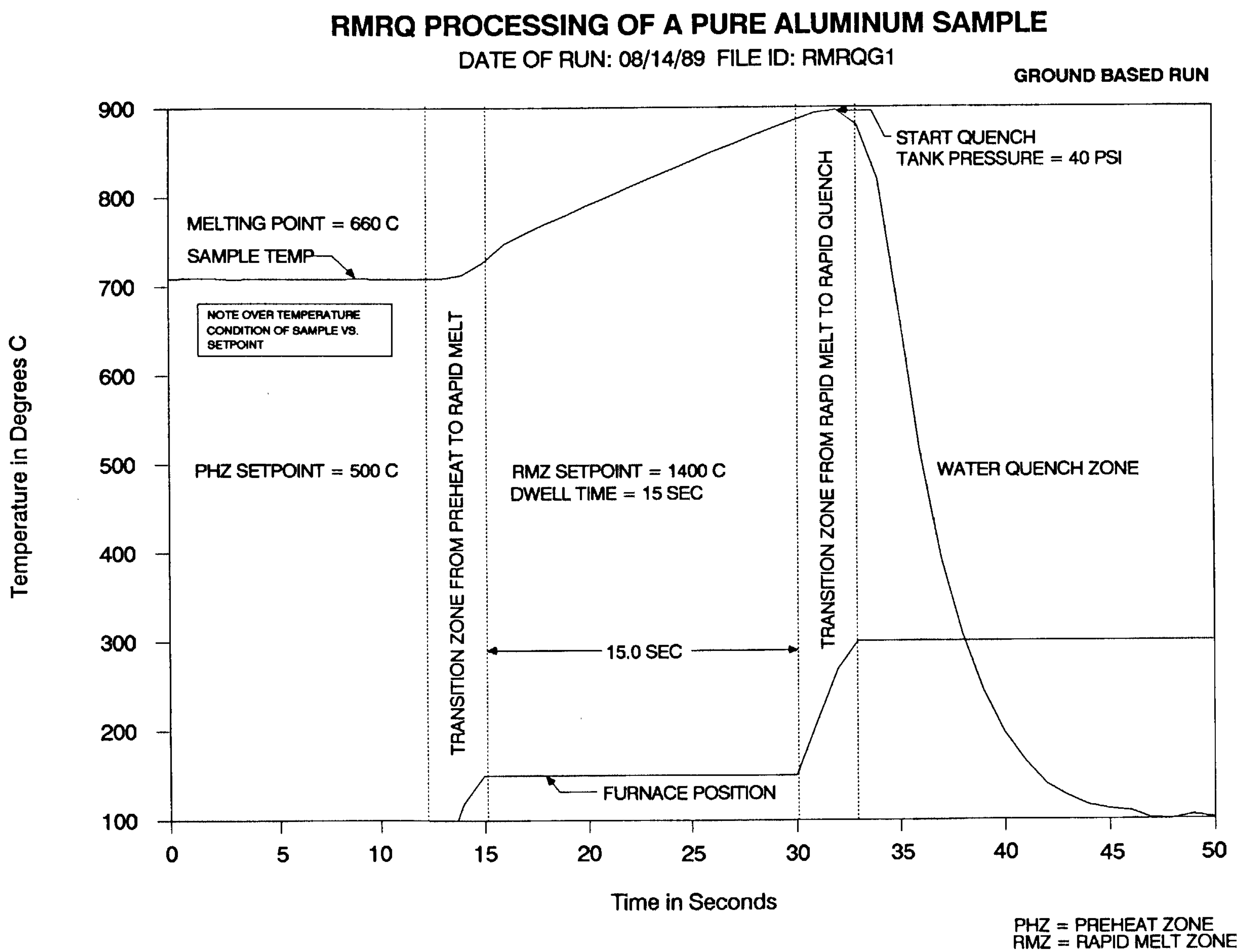

Figure 5: Thermal data from first ground based run of aluminum

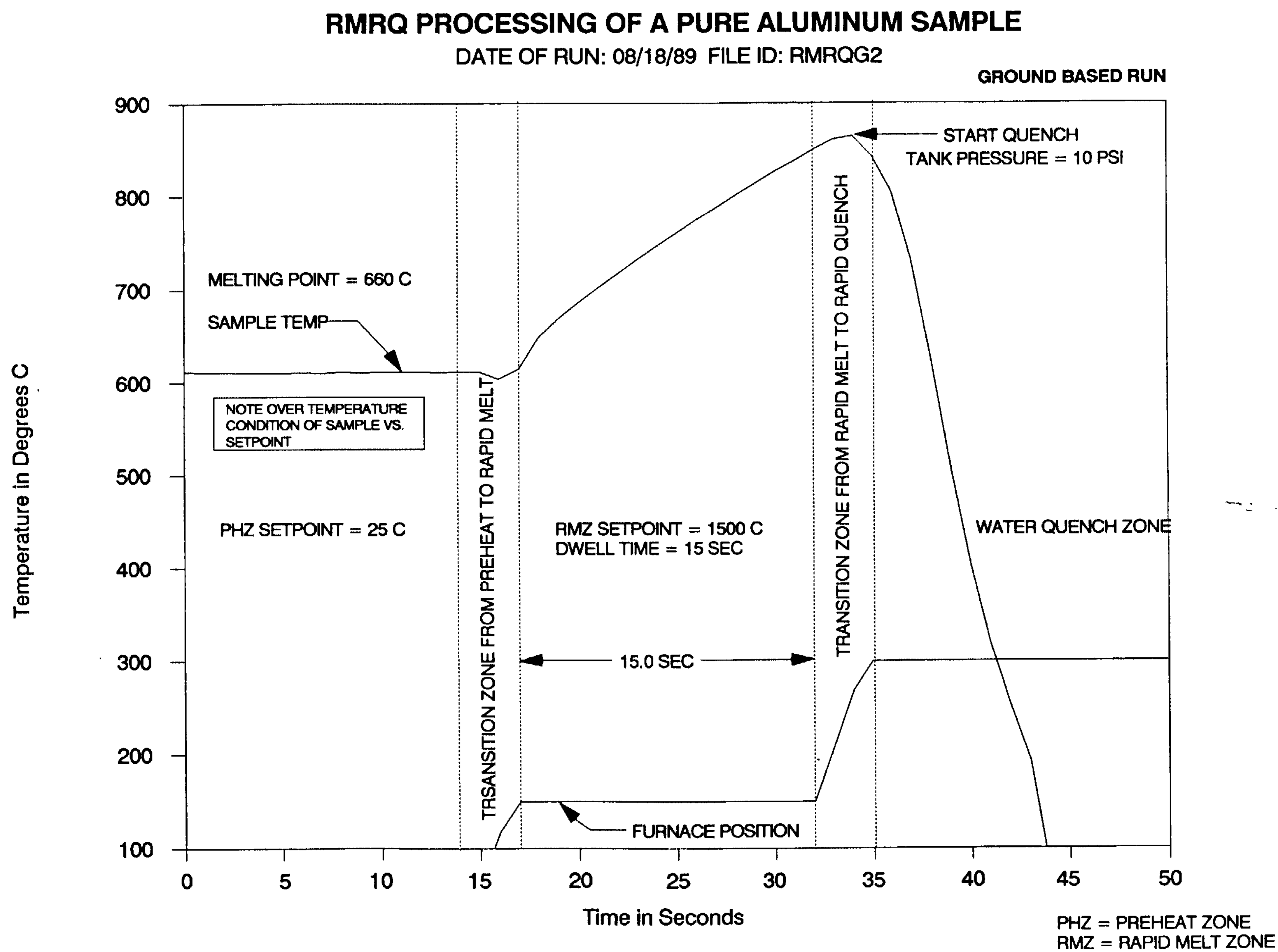

Figure 6: Thermal data from second ground based run

probably not suffice. A third run was attempted; however, due to the failure of several temperature control thermocouples, the run was aborted.

The conclusions drawn from the previous three graphs dictated that two modifications needed to be performed to the furnace canister internal design. First the booster heater located at the bottom the rapid melt zone (initially called the Variable Quench Heater) needed to be relocated to the top of the preheat zone. Second, better thermal insulation needed to be implemented to reduce the amount of heat flux (loss) from the rapid melt zone into the preheat zone. Ideally the rapid melt zone should have been located on top of the preheat zone in the first place. This would have eliminated the problem of the rapid melt zone overheating the preheat zone by gravity induced thermal convection. In addition, new temperature control thermocouples also needed to be installed since three of the six had failed. In August the furnace canister was removed from the RMRQ assembly, dismantled and the modifications performed.

Section 2.6.3: Thermal Profiles After Modifications

Upon reinstallation of the furnace canister into the RMRQ a series of thermal profiles were performed to determine the effectiveness of the modifications. First the results of relocating the booster heater were collected and plotted. Referring to Figure 7 the improvement of the isothermal zone with in the preheat core is unmistakable when compared to the old data in Figure 4. In addition Figure 8 indicated the effect on the isothermal zone when the setpoint of the booster heater is

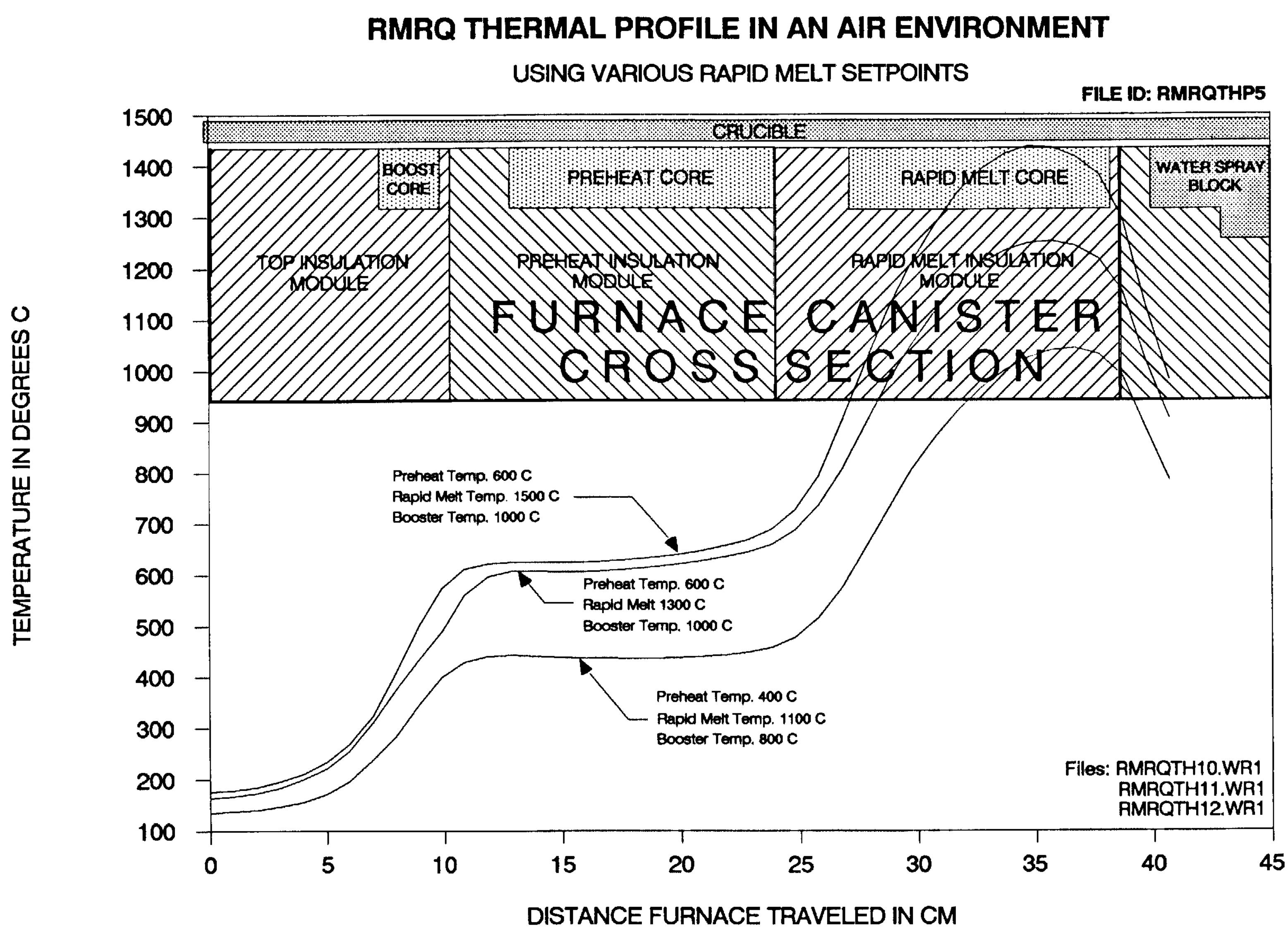

Figure 7: RMRQ thermal profile after modifications

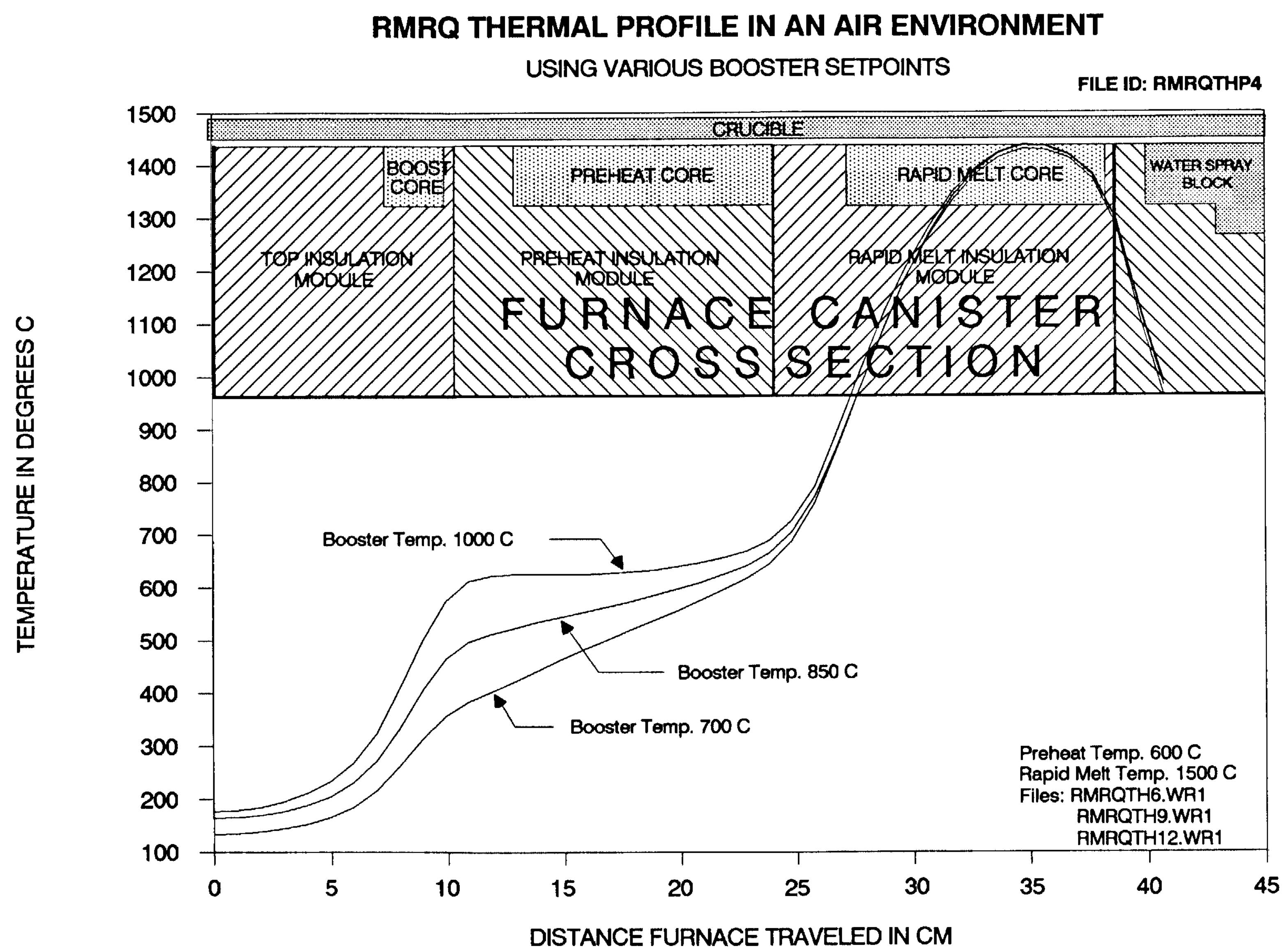

Figure 8: RMRQ thermal profile using various booster setpoints

changed. Note that the setpoint for the booster needs to be set 400^{o} C higher than the preheat core before an isothermal zone is achieved in this case.

Section 2.6.4: Results of Ground Based Runs with Modifications

Subsequently a series of ground based runs were performed using a pure aluminum sample instrumented with a type B thermocouple. It was learned during the review of file RMRQG3 that a vacuum is imperative for the rapid quench phase to work. It appears that a water spray by itself is not enough. Using the same sample a second run was performed (RMRQG4) using the same conditions; however, a vacuum source was made available. The results of that run is presented in Figure 9. Results indicated that all requirements were met that were necessary for a successful experiment.

1. The sample temperature remained below the melting point while within the preheat core.
2. The sample was heated to 825^{o} C and quenched to below the melting point in 25 seconds.

Having determined that the RMRQ system is technically functional the next step was to process several aluminum composite alloys prepared by Dr. Morel. This particular alloy was composed of 8% iron, 1% vanadium and 2% silicon with the balance being aluminum (sample ID C359). The melting point was thought to be approximately 660^{o} C - the same as pure aluminum however in reviewing the thermal data it was clearly higher. The samples were cut to 3 cm lengths and processed in the RMRQ. In January of 1990 several runs were completed prior to the flight experiments. Experiment run identified at RMRQG7 (Figure 10)

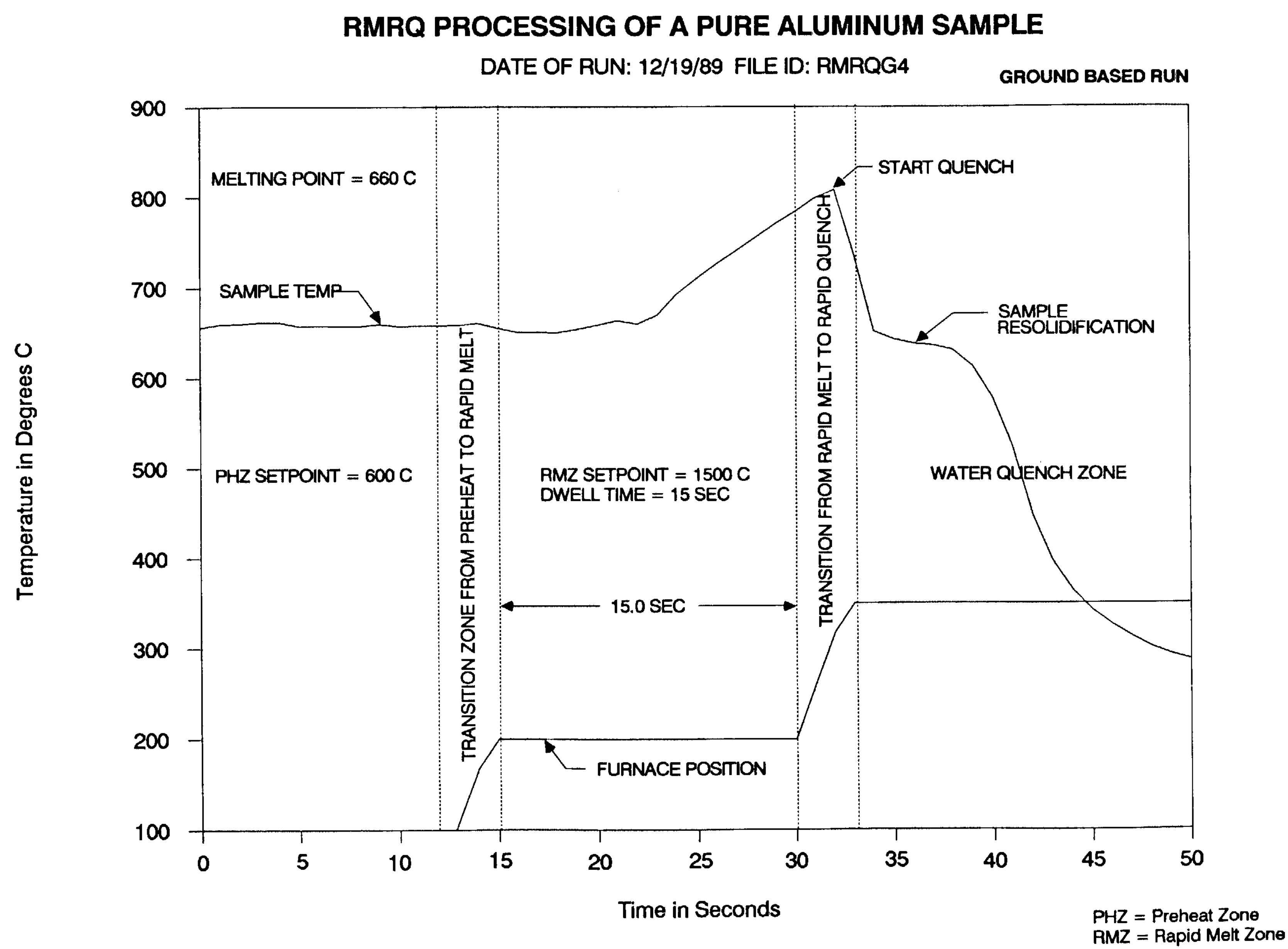

Figure 9: Thermal data from fourth ground based run

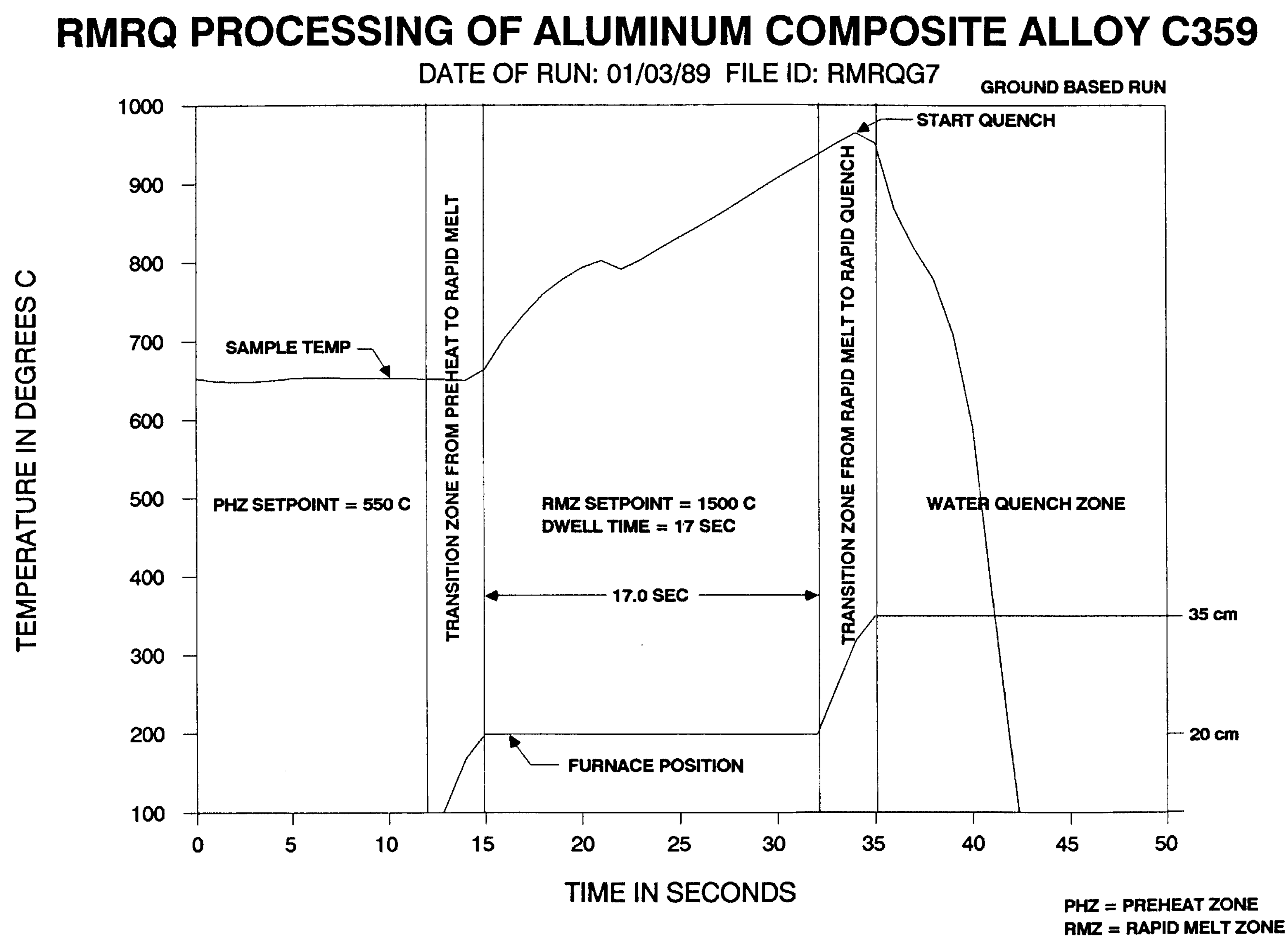

Figure 10: Results of RMRQ processing C359 alloy

is a typical example. Note that during the melting phase of the experiment a thermal arrest can be clearly seen around the 800^{o} C range.

Section 2.7: Results of Flight Based Experiments

During the week of January 7th, 1990 the RMRQ was flown for the first time aboard the KC-135. Two aluminum composite C359 alloys from Dr. Morel were processed with good results. Figure 11 presents the results of sample RMRQF1. The "up/down" accelerations are included in the graph and confirm that the sample was melted and resolidified within the one low g period.

Three main problems have been identified as result of this initial flight period and include:

1. Excessive time for the furnace to heat up to the required temperatures, typically 3 hours.
2. Incompatibility with JSC power converters due to the low resistance value of the heating elements.
3. Computer based temperature controller is not stable and does not meter the current flow during initial heat up. This in turn will cause premature failure of the heating elements.

After trying to use either of the two 400 Hz to 60 Hz power converters provided by JSC the unit supplied by MSFC to power the welding experiments was found to be the only one which could power the RMRQ. This was due to it having been modified to except power surges without shutting down. The problem arises in that while the RMRQ is in use none of the welding experiments can be conducted. In addition the 3 hour heat up times created logistical problems with ground crew operations. Temperature stability was also a problem in that the furnace temperature

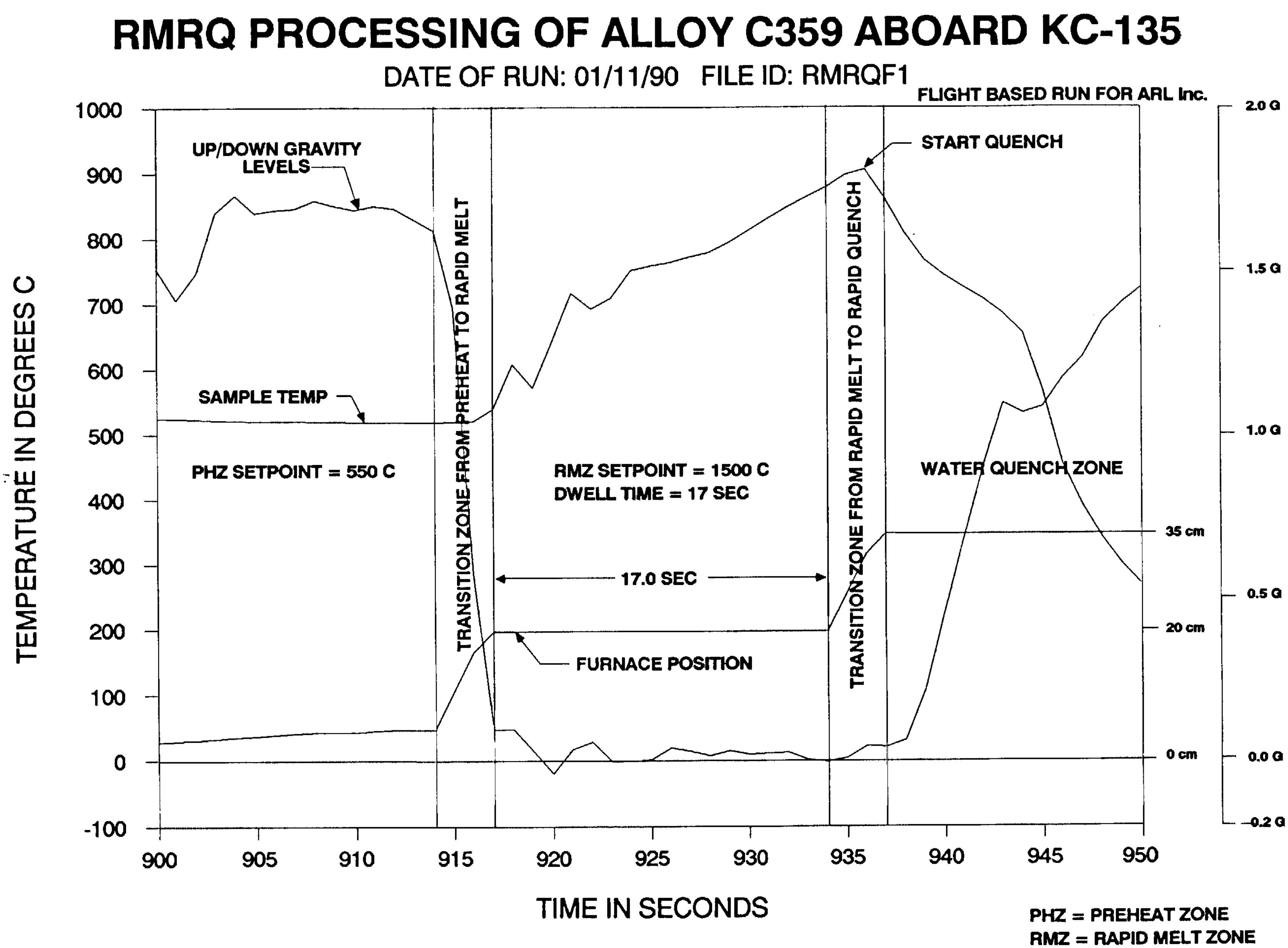

Figure 11: Results of first flight based processing of C359

drift was greater than 50 degrees at times. Installing off-the-shelf temperature controllers would solve this problem.

Section 2.8: Required Improvements

The following is a list of suggested improvements to the RMRQ system which will allow the maximum capability to be realized. The first and second items are of primary importance in that before the RMRQ can fly again they must be completed.

1. Install three off-the-shelf temperature controllers to control the RMRQ heater cores replacing the existing computer controller. This would provide quicker heat up times and much better thermal stability once at temperature. By purchasing power controllers which possess soft start phase angle firing the power incompatibility with the JSC 400 to 60Hz converters would also be solved.

2. Increase the maximum operating temperature of the heater cores from 1600^{o} C to 1800^{o} or perhaps even 1900^{o} C by using 0.045" diameter Pt/50%Rh alloy wire. This will allow the processing of the higher temperature Al-Ni based alloys. At the present time only the lower melting point aluminum alloys can be processed.

3. Rebuild the helium purge system to include the purging of the furnace canister assembly. Presently only the sample crucible is being purged.

4. Several improvements are needed to the control software to allow better flexibility in experiment parameters.

5. Add an internal high density floppy drive to the computer. At the present time a portable drive, shared between the RMRQ and TPF, has to be connected externally. This mode is more expensive and inefficient than two internal high density drives.

6. Relocate the water quench supply from the separate pallet onto the RMRQ assembly. This will eliminate the need for the separate pallet and thus simplify the overall system.

7. Replace all of the thermocouple signal leads with properly shield cables. This will reduce stray signal noise and provide a cleaner signal for the computer to record.

Section 3.0
Tasks Performed to the TPF System

Prior to beginning any work on the RMRQ furnace several modifications were perform to the TPF system. This furnace is essentially a directional solidification furnace with a video camera located in the field of view where the solid-liquid interface should be present during a processing run. This furnace was designed to process polymer compounds at relatively low temperatures however to date no such materials have been processed. Beginning in December of 1988 assistance was provided to Charles Cozean to prepare the TPF for it first flight in April of 1989.

Section 3.1: TPF Heater Modifications

Modifications to the Transparent Polymer Furnace were of a much lesser extent then the RMRQ. Much of the initial testing of the furnace had already been performed by Mr. Cozean and the problems identified. Initially this furnace was designed to operate no higher than 600^{o} C. However a requirement placed by Dr. Dave Matthieson of GTE required the furnace to be capable of reaching a temperature of 1100^{o} C. His intentions were to process electronic alloys (InSb) and record the interface shape and wetting phenomenon during varying g levels in the KC-135. It was determined that in order to view the solid-liquid interface with the video camera a specially designed heater core had to be fabricated. This heater was designed to concentrate the windings near the bottom of the core. In so doing a hot zone was established at the bottom, outside of the furnace canister and therefore located the interface in the field of view for the video camera. Modifications to the furnace were completed by fabricating two heater cores (one backup). In addition special quartz cylinders had to be fabricated and installed to reduce the amount of heat loss near the interface region. To improve the camera lighting conditions, the majority of the quartz was frosted leaving a narrow band for the camera view port. This reduced the glare caused by the fiber optic light source.

Section 3.2: Addition of Time/Date Generator to Video System

One serious lack in the data acquisition part of the TPF system was the inability to correlate g level to video data. As result the investigator could not determine accurately what part of the sample was processed in low g and or high g. To solve this problem a Panasonic Time/Date Generator was purchased and mounted into the electronics rack and integrated into the video system. This provided a time/date overlay onto the camera image and thus recorded on the VCR. This model included a battery backup so that in the event of a power glitch or failure an accurate account of the event would be recorded.

Section 3.3: Addition of a Battery Backup for the Computer

While a UPS system was ordered it did not arrive in time for the first KC-135 flight. As result of the inevitable power glitches aboard the KC several problems transpired during the flight. Upon return from Houston the unit was installed into the electronics rack in time for the June 1989 KC-135 flights.

Section 3.4: Addition of an Interface Demarcation Unit

In crystal growth the furnace translation rate rarely equals the microscopic rate of crystal growth. In order to determine the actual crystal growth rate, the technique of interface demarcation has been developed. This consists of sending a short duration current pulse through the growing crystal at a known frequency. This causes a segregation effect at the interface of alloys. After the samples has been processed, cut, polished, and etched, this segregation effect appears as a line when viewed with interference contrast microscopy, and also demarks the interface shape. By measuring the distance between these lines and knowing the time between pulses the actual growth rate can be determine.

Several years ago such a unit was built by Draper Laboratories for Dr. Matthieson when he first began his research using the ADSF on the KC-135. At that time the interface demarcation unit was mounted in the ADSF data acquisition system where it remained until recently. It was removed and reinstalled into the TPF electronics rack in time for the April 1989 KC flight.

Section 3.5: Modification of Data Processing Software

Associated with both the TPF and the RMRQ systems was a data reduction program which would take the data stored by the computer and convert it into a format which could then be imported into a SYMPHONY or LOTUS 1-2-3 spreadsheet program for analysis. However in its initial form the program required considerable modification before the data was easily accepted by the spreadsheet software. Jim Chamberlain and Van Nanny of General Digital Industries were the original two authors of the program and at that time were not too clear as to what was required of it. They were subsequently subcontracted by UAH to modify the program per clearly outlined requirements. Modifications to the software were completed and are acceptable.

Section 3.6: Addition of a Video Camera Cooling System

During the June 1989 flight of the TPF system it was noticed that as the camera heated up due to heat from the furnace, the video image would degrade to the point where nothing could be distinguished. This would usually occur when the TPF cover was on and the furnace had been heating for about an hour.

Using the parts removed from the RMRQ cooling system a new cooling system was built to prevent the camera from being exposed to the heat from the furnace. Using Tygon tubing, a water jacket was wrapped around the camera body and circulated with cooling fluid in a closed loop system. Ground testing determined that the camera remained cool even when the furnace had been heating for several hours.

Section 3.7: Suggested Improvements

In order to maximize the operation of the TPF while either on the ground or aboard the KC-135 a number of modifications are needed. They include:

1. Install a remotely controlled X-Y-Z translation stage to the video camera mount. This would allow precise focusing of the camera with respect to the sample. At the present time two screw must be loosened and the

camera manually adjusted. In order to perform this task the viewport must be removed from the furnace canister. This is a breech of containment during the flight and a safety concern.

2. Improve the lighting conditions for the camera by adding a second fiber optic light source to the existing one.

3. Rebuilt thermocouple signal circuits - many of the present connections are not alloy compensated. In addition most of the signal cables are not shielded and should be replaced.

4. Improve on the insulation of the furnace to reduce the amount of heat loss from the heater core and the heat up time.

5. Add an internal floppy drive to the computer.

6. Improvement is still warranted for the software. A number of changes are still needed.

7. Install an off-the-shelf temperature controller to improve on the heat up time and thermal stability.