DESIGN AND IMPLEMENTATION OF A LOW-GRAVITY SOLIDIFICATION EXPERIMENT PACKAGE FOR THE F-104

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ABSTRACT

The use of the F-104 Interceptor at Dryden Flight Research Facility for low-gravity materials processing experiments has been extended to include alloy solidification studies above 1000°C. The F-104 can provide up to 60 seconds of low-gravity, but requires a unique experiment package for integration into the aircraft, both physically and electronically.

This paper describes the current research with the F-104 experimental furnace system which has been used to process cast iron samples for the John Deere Company. Results of these test are shown to demonstrate the capability of the facility and its operation.

DISCUSSION

The F-104 Solidification Experiment Package is a semiautomatic self-contained system designed to melt down particular alloys during the flight ascent of the F-104 aircraft and subsequently during the low-gravity maneuver (10^{-1} to 10^{-3} g's) to quench the sample so as to allow solidification of the alloy in a low gravity environment. The system is basically a high temperature furnace controlled by an Omega automatic type S temperature controller, a pressurized helium quench system, and a signal conditioning circuit designed to amplify the millivolt signal coming from the S thermocouple up to a voltage level suitable for telemetery transmission to the ground.

All electronics are designed or have been modified to operate with the 28 VDC supplied by the aircraft or the ±15 volts supplied by the power converter in the package. The Omega Model 6103 temperature controller has been modified to operate with +15 volts DC while the Analog Device AD522A signal amplifier uses both ±15 volts DC. The Ohmic model JR 125 reference cold junction is battery powered and is energized via a control relay. This unit is self-contained in that it contains its own internal battery rated for 5000 hours of operation.

For the current application the package is calibrated to meet the needs of experiments desired by the John Deere Company. These experiments require the furnace to attain a temperature of 1350°C ± 10°C and maintain that temperature for no less than 2 minutes and no more than 10. Once the furnace is energized on command from the co-pilot it takes less than 11 minutes to reach the maximum temperature of 1350°C. These values can vary ±2 minutes depending on sample type and voltage conditions of the aircraft. A typical flight run would include the co-pilot activating the furnace via a toggle switch on his instrument panel about 16 to 18 minutes prior to entering his low-gravity maneuver. Then 30 ± 5 seconds prior to entering low gravity the co-pilot would turn the furnace off and activate the quench solenoid valve via a second toggle switch. With the solenoid valve now open, helium will flow at a present rate around the furnace and cool the cast iron sample at a controlled rate. If the timing is correct the sample should solidify during the optimum low-gravity period. This period is a 40 second window in the middle of the total 60 second maneuver. The first and last 10 seconds are considered poor low gravity due to wing rock of the aircraft. Once the furnace is turned off only data acquisition occurs and the helium valve is left open until the supply tank is exhausted. Upon landing, the experiment package is removed from the aircraft and the processed alloy sample is then replaced with a new one.

Figure 1 pictures the loading of the F-104 experiment package into the "E" bay of F-104 No. 825. Originally this bay was loaded with navigational equipment packages. Overall size limitations are 22" L x 16" H x 14" W and approximately 50 pounds. The only power available to the package is 28 VDC at 30 amps.

Figure 1

Figure 2 displays the package as it sits in the "E" bay.

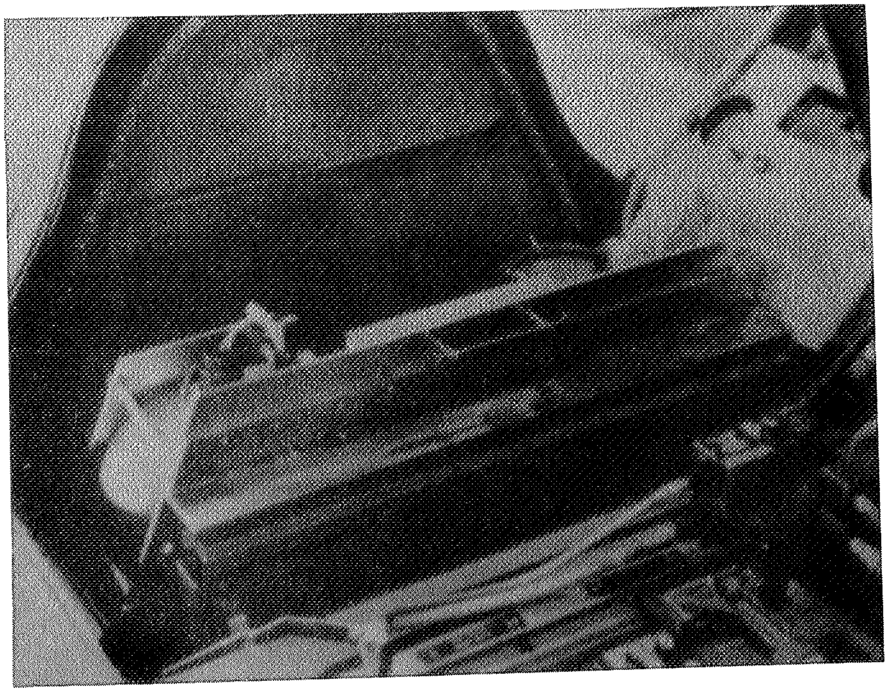

Figure 2

Sample temperature and accelerometer data are telemetered from the aircraft to the mobile telemetry van where it is recorded on digital tape and strip charts. Close monitoring of the temperature data and direct voice contact with the pilots allows for the required timing logistics. Pictured in Figure 3 is one of the Dryden engineers noting major events on the strip charts.

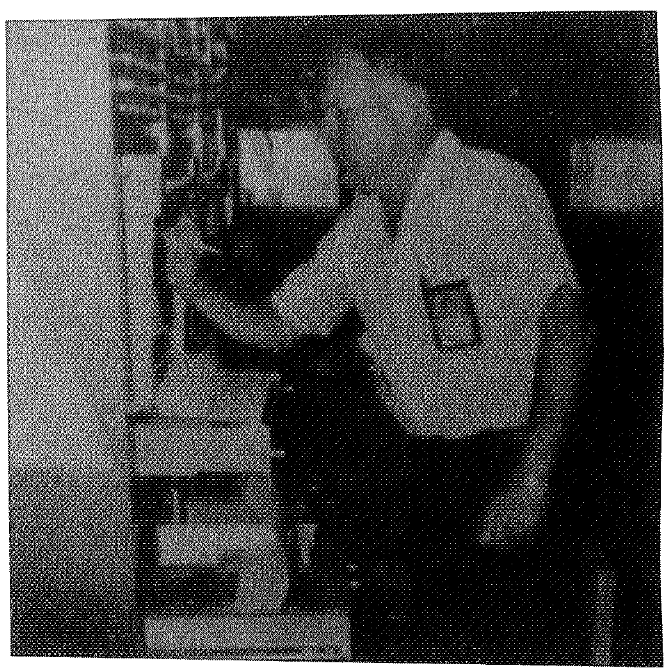

Figure 3

F-104 No. 825 is a two seat aircraft and it takes both the pilot and the co-pilot to fly it. During the maneuver g forces may reach 3-g's during pull up and pull out. Because of this the front pilot must use both hands to maneuver the aircraft and the co-pilot controls the engine throttle. Due to the possibility of an engine flame-out the pilots must be ready at all times to perform a dead stick landing on the dry lake bed.

Figure 4 shows the two pilots getting ready for flight. During the low-gravity maneuver of the aircraft altitudes may reach as high as 72,000 feet. As a result the pilots must wear special pressure suits and require the full support of life support systems.

Figure 4

The two diagrams in Figure 5 represent typical gravity levels experienced by the aircraft and experiment package during a low-g maneuver. The top graph is an actual strip chart recording taken during a low-g maneuver. The lower graph gives a broader perspective.

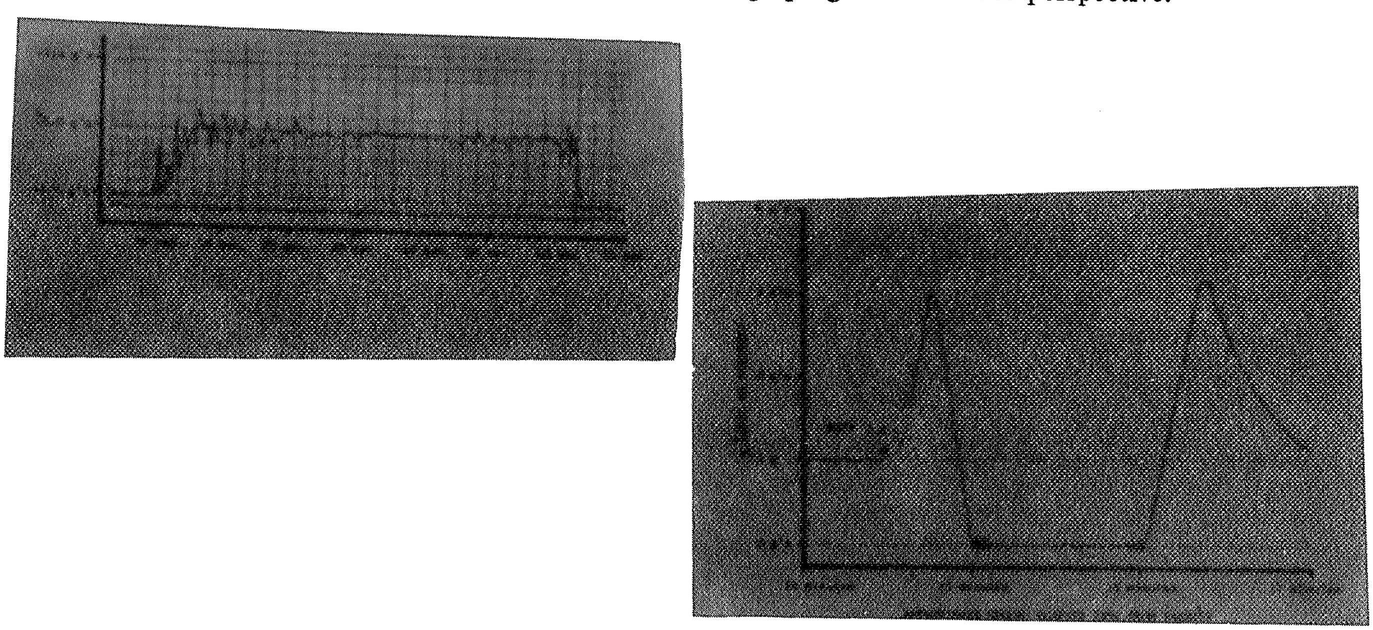

Figure 5

Figures 6 and 7 are photomicrographs with their cooling curves of nodular cast iron processed in the F-104 experiment package during normal 1-g gravity. The cast iron is of nodular type supplied by the John Deere Company who currently has a technical exchange agreement with the Marshall Space Flight Center. The sample alloys were processed at the Johnson Environmental and Energy Center, UAH, and represent only a small part of the ground based testings of the F-104 experiment package. It was through these based runs that it was discovered that the effects of localized chilling was caused by the methodology used in quenching the processed samples. Figure 6 micrographs show 100% nodular iron which was quenched at a rate of 76°C/minute. Figure 7 is of the same alloy only quenched at a faster rate of 261°C/minute. It can be seen clearly that sample is no longer 100% nodular but rather 20% nodular grey and 80% white iron. Since then a major modification in the quenching system was implemented. By changing the flow characteristics of the helium gas, subsequent tests have shown a major reduction in the chill zones and white iron formation. Samples have been quenched as fast as 200°C/minute with little or no white iron formation and no chill zones. The first time the F-104 experiment package was flown this problem had as yet not been discovered and as a result the processed samples were difficult to interpret.

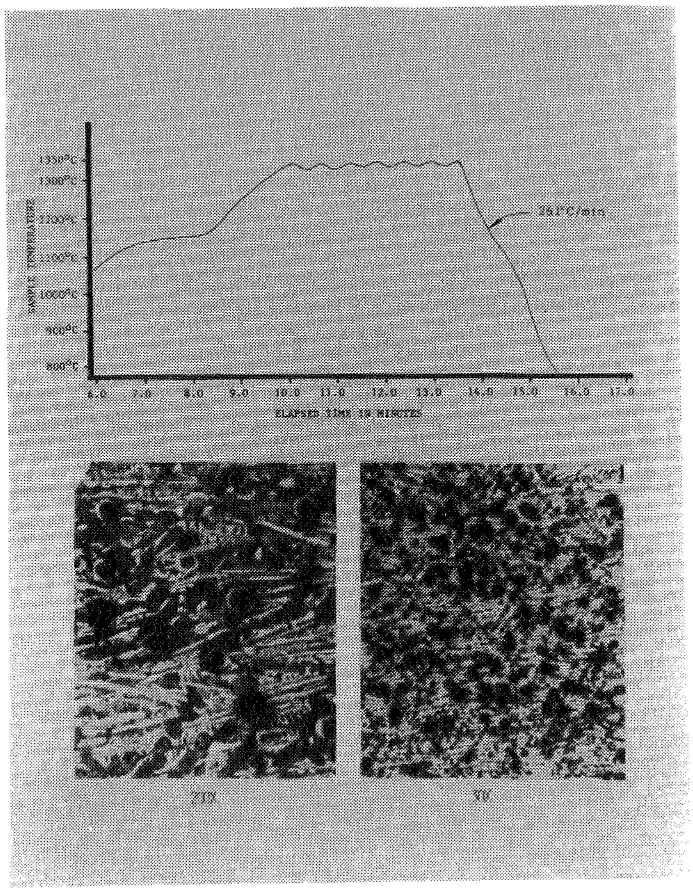

Figure 6

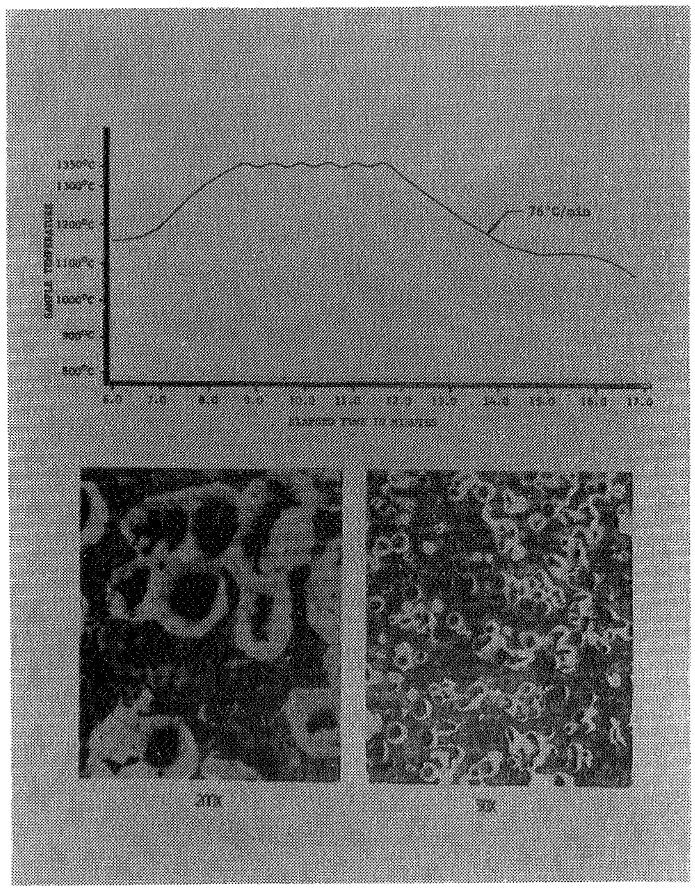
SAMPLE TEMPERATURE
1350°C
1300°C
1200°C
1100°C
1000°C
900°C
800°C
76°C/min
6.0
7.0
8.0
10.0
11.0
13.0
14.0
15.0
16.0
17.0
ELAPSED TIME IN MINUTES

Figure 7