

# Performance of a Solidification Furnace Developed for Sounding Rockets

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**Abstract** Brazil has a Microgravity Program mainly based on experiments using sounding rockets. This paper presents a brief account of the Program and the experiments made on the Brazilian rockets. Up to now three missions carrying a total of 26 experiments were made. In all flights a fast solidification furnace, capable of producing temperatures up to 900°C, was tested with semiconductor and metal alloys. This paper describes the construction and the performance of that furnace during the last parabolic flight, occurred in 2010. The solidification furnace is now qualified and ready to be used by other institutions in sounding rocket flights.

**Keywords** Suborbital flights · Solidification furnace · VSB-30 sounding rocket · Brazilian microgravity program

## 1 Introduction

The Brazilian Microgravity Program was established in 1998 by the Brazilian Space Agency (AEB), aimed to provide a regular sequence of flight opportunities to the Brazilian scientific community to perform experiments and to test hardware facilities in microgravity environment.

The Program supports the Brazilian microgravity activities by selecting and following the experiments since their initial design phases up to the flight mission, given also partial financial support for the approved projects (<http://www.aeb.gov.br>).

Their activities are technically assisted by institutions such as the Brazilian Space Research Institute (INPE) and the Aeronautical and Space Institute (IAE).

The Microgravity Program contemplates missions on ISS/Soyuz and on Brazilian made sounding rockets. Up to now only one flight, described elsewhere (Bandeira et al. 2007), was made at ISS in 2006, carrying eight experiments and the first Brazilian astronaut.

The first parabolic flight was in 2002 and eight microgravity experiments were selected by the Program 1st Announcement of Opportunity (AO), embracing areas such as biology, material sciences and transport phenomena. During the 4 min flight, high speed telemetry and real time high resolution digital video were offered. Into the proposed scenario, the payload would land at the

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**Fig. 1** Brazilian sounding rockets made at IAE. The VS-30 was used in the 1st AO and the VSB-30 was employed in the 2nd and 3rd AO's. The VSB-30 actual picture was from the 3rd AO, showing the cooling bags used for biological experiments during the waiting time in the launching platform



sea with the aid of parachutes and be recovered by helicopter.

The experiments were launched by a one-stage Brazilian VS-30 sounding rocket (3 to 4 min of microgravity), made by IAE, from the Alcântara Launching Center. Unfortunately, a failure resulted in the platform loss at the sea, making impossible the experiments recovery. A second flight was done in 2007 and a third in 2010 with a more powerful two-stage sounding rocket denominated VSB-30 (6 to 8 microgravity minutes). The VSB-30 is capable of transporting payloads with mass

up to 400 kg during about 360 s in a ballistic flight above 110 km. The rocket transports a payload, based in the TEXUS technology, made by DLR/MORABA in cooperation with IAE, used to monitoring the flight, into a nominal trajectory (Corrêa et al. 2005).

Figure 1 shows these rockets, while Table 1 summarizes some of the main characteristics of the Brazilians operational rockets for microgravity purposes.

Figure 2 shows the payload that is used to carry the microgravity experiments on the VSB-30

**Table 1** Rockets characteristics without payload

Rocket	Rocket stage characteristics				
	VS-30	VSB-30		VS-30/Orion	
Stage	–	1 <sup>st</sup>	2nd	1st	2nd
Rocket motor	S30	S31	S30	S30	Orion
Length (mm)	4094	3310	4094	3700	2657
Diameter (mm)	557				356
Mass (kg)	1183	995	1236	1166	425
Microgravity time above 110 km (s)	180	450		450	
		300 kg payload	300 kg payload	200 kg payload	
Burning time (s)	19	12	19	19	22
Action time (s)	28	18	28	28	26
Apogee (km)	150	330		330	



**Fig. 2** Microgravity experiments payload at INPE's Tests and Integration Laboratory

rocket. After the parabolic flight it falls on the sea aided by parachutes and is recovered by Brazilian Air Force helicopters.

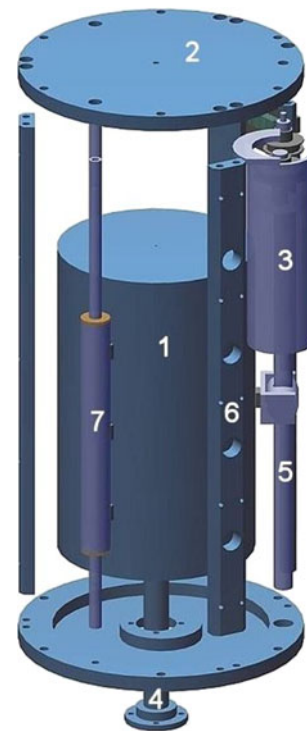
## 2 Solidification Furnace

The objective was to project, construct and qualify a compact furnace as a permanent facility to the sounding rockets microgravity program. The proposal was made by a group of the Associate Laboratory of Sensors and Materials (LAS) of the Brazilian Space Research Institute, and the idea was to have a several user furnace facility for the Brazilian groups that worked in that area. The furnace purpose is to melt and solidify metals and semiconductor alloys with fusion point up to  $900^{\circ}\text{C}$ . The furnace should be capable of a fast cooling, compatible with the short microgravity times of suborbital flights, in order to solidify sample up to 10 mm diameter and up to 120 mm length.

The tubular furnace is heated and controlled from the ground through the rocket umbilical cable until it reaches the desired temperature. After

launch the temperature is kept by thermal inertia. When the microgravity environment is reached, a signal starts the movement of the hot part of the furnace and a fast sample cooling is obtained. The experiment temperature is monitored by two thermocouples and their signals are stored in an internal data-logger as well as sent to ground by telemetry.

The exploded drawing of the furnace is shown on Fig. 3. It comprises the tubular furnace itself made of stainless steel, having 110 mm of diameter and 200 mm length. The materials processing chamber is a ceramic tube with 20 mm diameter, running along the center of the whole furnace. The upper 120 mm part of the ceramic tube is involved by a shielded electrical resistance and quartz fiber is employed as thermal insulation. The remaining resistance free portion produces a thermal gradient in the order of  $40^{\circ}\text{C}/\text{cm}$ . There is an external structure holding the furnace, permitting its up and down movement with the aid



**Fig. 3** Exploded view of the solidification furnace: 1 – furnace; 2 – top of the external structure; 3 – driving motor; 4 – sample holder; 5 – jackscrew; 6 – structural bars; 7 – sliding guide bars

of an electric motor. This structure also supports a stainless steel sample holder tube placed inside the ceramic cavity. The system has a total diameter of 180 mm and a total length of 340 mm, weighting 12 kg.

Figure 4 shows the furnace in the two positions described above. During ground and ascending rocket phase the furnace is at the bottom position, completely involving and heating the sample. As soon as the microgravity environment is reached, the motor drives the furnace to the upper position in less than 8 s, leaving the sample exposed to cool down.

At the side of the solidification furnace appears the electronics control box. It contains a data-logger for the two type K thermocouples, batter-

ies for the furnace drive motor, timer for motor stopping, amplifier for telemetry temperature signals and the circuit for the control thermocouple connected to the controller unit and a 110 DCV source that powers the furnace from the ground, providing a temperature stability of  $\pm 1^\circ\text{C}$ .

### 3 The Maracati Mission

The third AO flight had taken place on December, 2010 and was codenamed Maracati.

A VSB-30 rocket carried ten microgravity experiments from Brazilian universities and research centers. The apogee was 242 km and the total flight time 18 min, from which 6 min in microgravity. The payload fell on the sea and was rescued about 1 h later.

Among the experiments was the Solidification Furnace described above made at the LAS/INPE. The furnace was projected, constructed and fully qualified for space flight at INPE's facilities.

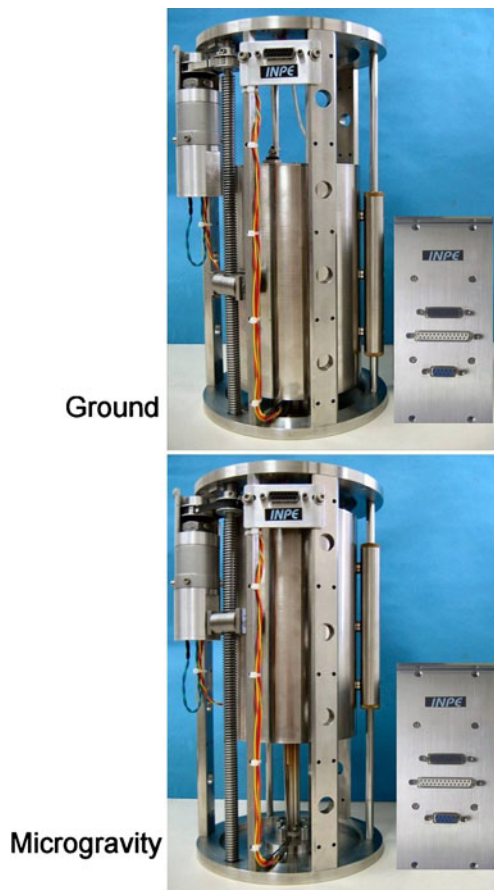
In this flight a solidification experiment with two eutectic alloys was carried out. The eutectic composition (10.9 Pb at.%) of the PbTe alloy with a fusion point of  $410^\circ\text{C}$ , and the eutectic composition (26.1 Pb at.%) of the PbSn alloy, fusion point of  $183^\circ\text{C}$ , were used.

Each sample, with 13 g mass, was sealed under vacuum within a quartz ampoule with 60 mm length and 10 mm diameter shown on Fig. 5 and the furnace temperature gradient is shown on Fig. 6.

The ampoules were fitted inside the stainless steel tube sample holder and the furnace was heated in the ground to  $500^\circ\text{C}$ , using the rocket umbilical cable, 30 min before launch. The sample temperatures were monitored by the on-board data-logger as well as by telemetry.

The microgravity level attained was in the order of  $10^{-4}$  g which was enough to cause predominance of Marangoni convection over the thermal and constitutional gravitational dependent convections. That will allow the study of the superficial tension influence in the PbTe and PbSn eutectic alloys.

The samples will be analyzed by several techniques such as x-ray diffraction (XRD), scanning electron microscopy, x-ray dispersive energy spec-



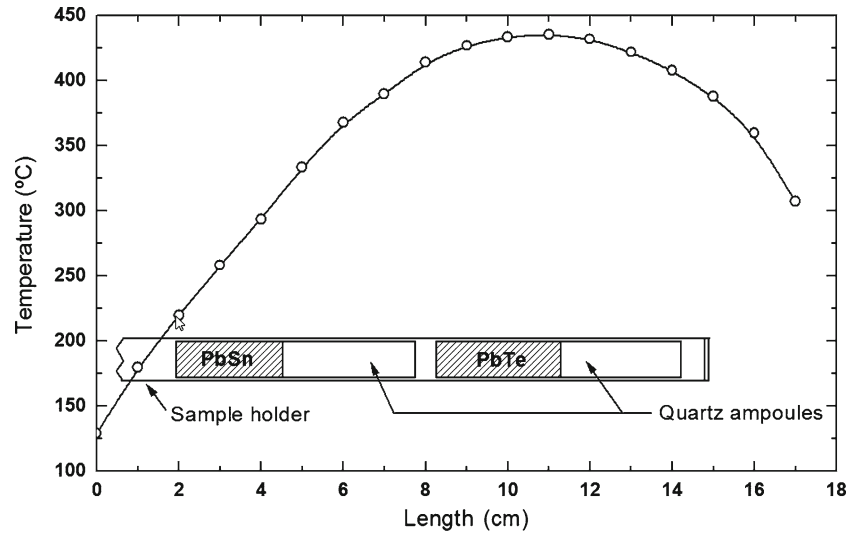
**Fig. 4** Solidification furnace in its two working phases: at the bottom heating the sample during ground and ascending periods, and at the top permitting a fast sample cooling during microgravity



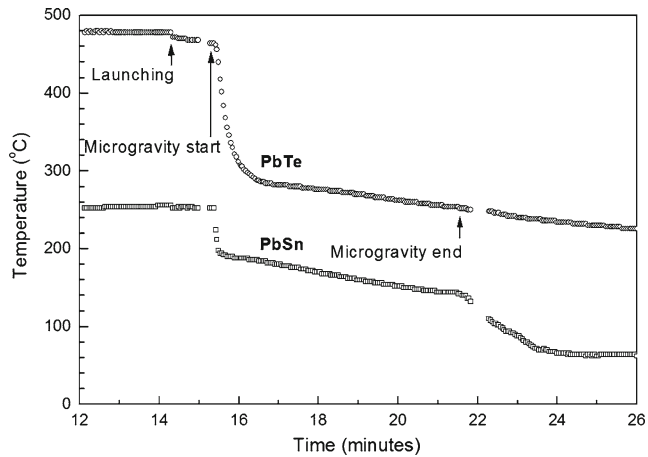
**Fig. 5** Eutectic  $Pb_{10.9}Te_{89.1}$  and  $Pb_{26.1}Sn_{73.9}$  ampoules after the microgravity flight



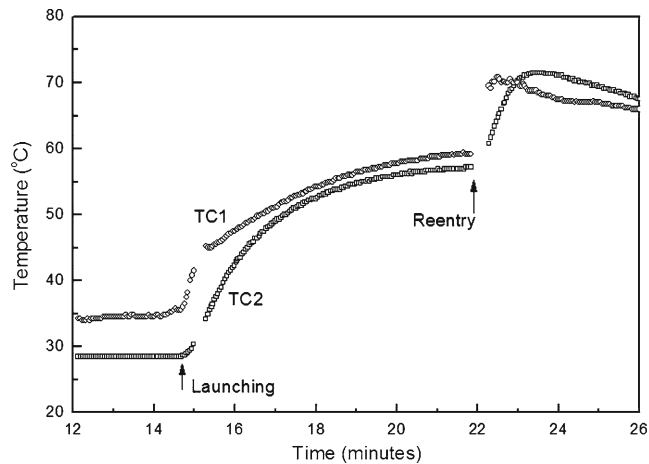
**Fig. 6** Temperature gradient of the solidification furnace showing the samples quartz ampoules position inside the sample holder



**Fig. 7** Telemetry data of the solidification furnace thermal cycle during the microgravity flight



**Fig. 8** Module temperature as measured by two thermocouples TC1 and TC2 located at the top and bottom module plates, respectively



troscopy (EDS), differential calorimetry (DSC), among others, and the results will be published elsewhere.

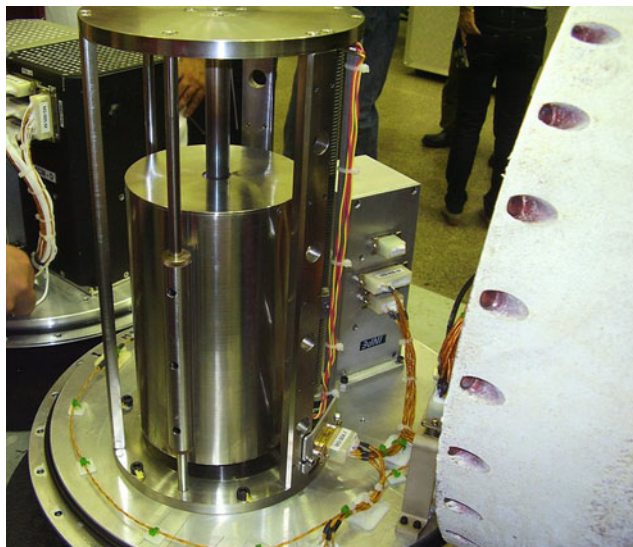
All launching procedures and phases were successful. In the moment the rocket was launched the furnace power was switched off. The two stage rocket worked nominally and the payload reached microgravity about one minute after take off. As the acceleration sensor detect the microgravity proper level it sent a signal to the furnace and the heater part traveled to the top of the system in 8 s, leaving the samples free to cool down. After 6 min the payload started the reentry process. The parachutes were opened at the proper altitude,

the payload fell and floated in the sea and was later recovered by a Brazilian Air Force diving team.

The telemetry data for the furnace thermal cycle is shown on Fig. 7 for both samples.

The cycle behavior was as expected, the furnace temperature having a small drop of about 10°C during the rocket ascending due to the one minute without power. Reaching microgravity, as soon as the furnace moved to the upper position, the temperature drop was of 150°C in 30 s for the PbTe alloy, allowing the fast cooling needed for the eutectic  $\text{Pb}_{10.9}\text{Te}_{89.1}$  and  $\text{Pb}_{26.1}\text{Sn}_{73.9}$  solidification experiment.

**Fig. 9** Solidification furnace just after the microgravity flight



One of the concerns was the overall module temperature where the furnace was located. Once several experiments, including biological ones, were nearby, the insulation has to be good enough to keep the module external walls inside the acceptable limit.

Two thermocouples TC1 and TC2 located at the module top and bottom plates, respectively, measured the temperature that the furnace caused to the encasing environment.

As can be seen by the graph on Fig. 8, during the ground phase the maximum temperature inside the module, on the top plate where the furnace was attached, was 35°C, well inside the limits. After launching and reentry the temperature increased to around 70°C due to the atmospheric friction.

Figure 9 shows the furnace in the system upper part position just after the flight. The steel tube, now outside the furnace, is the sample holder containing the samples. In the right side, the scorched payload module.

#### 4 Conclusions

The Solidification Furnace, provided by INPE to the Brazilian sounding rocket program, is now qualified and ready to be used by other groups that are interested in melting and solidifying semiconductor and metallic alloys up to 900°C in microgravity.

Already following this policy, the INPE's furnace was used to process experiments from the Pernambuco Federal University in the two first flights. In a vacant place inside the sample holder, an experiment for studying the thermal migration of metallic nanoparticles in a vitreous material (Oliveira et al. 2002 and 2007), was carried out together with narrow gap semiconductors experiments from LAS/INPE (Bandeira et al. 2002 and 2007).

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