Development of micro gravity experimental system from high altitude balloon and experimental report of spacecraft #2

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ABSTRACT

A new micro gravity experimental system called BOV (Balloon-based Operation Vehicle) is developed in ISAS/JAXA. BOV uses a free-fall capsule with double-shell structure to prevent influence of aerodynamic disturbance. Additionally, BOV is raised to 40km by a high altitude balloon to extend micro gravity duration to 30(or possibly 60) seconds. Thus we realize a medium duration micro gravity system with good micro gravity environment.

In this system, the most characteristic point is double-shell sturcture. The inner shell can fall freely since the outer shell measures the relative position with laser displacement sensors and is controlled by gas-jet thrusters not to collide the inner shell.

The BOV's project has run since 2004. The first flight to check the whole system was accomplished in 2006. The aim of the first flight was test of a high altitude balloon, communication and data handling system, control system, onboard electronics and operation. The second flight was also accomplished in spring 2007. The aim of the second flight is to verify the effectiveness of the proposed method and demonstrate the long duration micro gravity.

This paper presents the development of BOV's system and reports the result of the second flight for the new micro gravity experimental system.

高高度気球を用いた無重力実験装置の開発と 2 号機実験の報告

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概要

現在、宇宙航空研究開発機構/宇宙科学研究本部では新しい無重力実験装置 BOV(Balloon-based Operation Vehicle) の開発を行っている。BOV は無重力実験部として球体状のカプセルを持ち、カプセルが空力外乱の影響を受けないように 2 重構造の機体となっている。この機体は 30 秒 (可能であれば 60 秒) の無重力実験時間を実現するために高高度気球を用いて上空 40km まで上げられる。このような実験システムを実現することで、長時間の無重力実験がより良い無重力実験環境で実現される。

BOV のシステムにおいて最も注目するべき特徴はその 2 重構造である。外部シェルとなる機体は無重力実験カプセルとの相対距離を計測し、カプセルと衝突しないようにガスジェットスラスタによって制御される。これにより、実験カプセルは理想的な自由落下が可能になる。

この新しい無重力実験装置の開発は 2004 年から始まり、2006 年においては 1 号機の飛翔実験が行われた。この実験においては高高度気球、通信・情報処理システム、制御システムまたその他のセンサや全体の実験システムの確認が行われ、無事に実験システムが動作することが確認された。そして、2007 年の春には 2 度目の飛翔実験が行われ、本実験システムの目的である長時間の無重力実験の実現が検証された。

本稿ではこの無重力実験装置の開発と 2 号機実験の報告を行う。

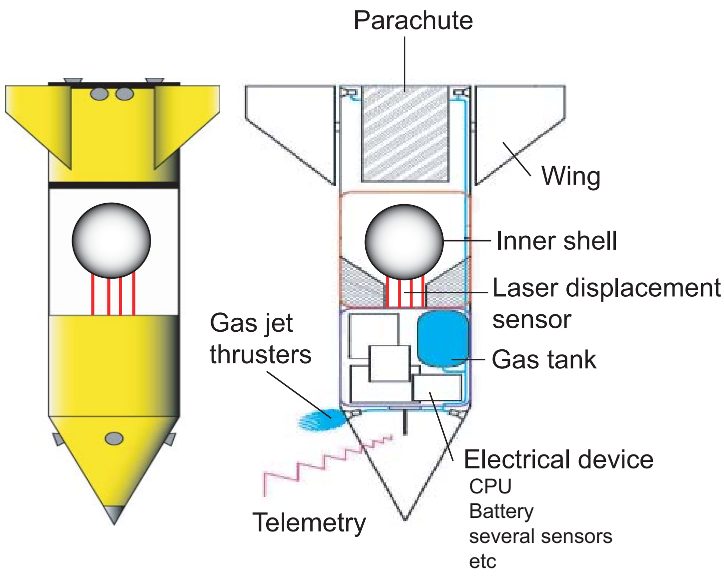

Figure 1: Overview of BOV(Baloon-based Operation Vehicle)

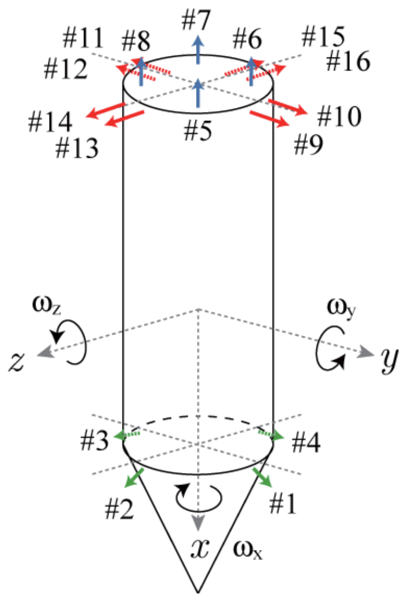

Figure 2: Distribution of thrusters in BOV

1 Introduction

This paper proposes a new micro gravity experimental system called BOV (Balloon-based Operation Vehicle). Today, there are many kinds of micro gravity test system, drop tower, parabolic flight, International Space Station(ISS) and so on. But these test systems are polarized: one hand is low cost but short span like a drop tower or not so good μG like a parabolic flight, the other hand is expensive but long span like ISS or satellite.

we propose a moderate cost and medium duration micro gravity test system with good quality μG which uses a free-fall capsule with double-shell structure to prevent influence of aerodynamic disturbance. Additionally, this system is raised to 40km by a high altitude balloon to extend micro gravity duration to 30(or possibly 60) seconds. Thus we realize a medium duration micro gravity system with good micro gravity environment.

This project has run since 2004. The first flight to check the whole system was accomplished in 2006. The aim of this flight was test of a high altitude balloon, communication and data handling system, control system, onboard electronics and operation. The second flight expected to achieve 30 seconds micro gravity was also accomplished on May in 2007.

This paper presents the development of BOV's system and shows the experimental results of micro gravity and consideration for effectiveness of BOV's system.

Table 1: Specification of BOV

length	5[m]
diameter	0.55[m]
wight	310[kg]
actuators	
gas jet thrusters	front: 4ch, rear: 12ch
wings(driven by motor)	4ch
sensors	
tempature	16ch
pressure	4ch
acceleration	3ch
Fiber optical gyro	3ch
laser displacement sensor	4ch

2 System Configuration

In BOV's system, the most characteristic point is double-shell structure in Fig. 1. The inner shell can fall freely since the outer shell measures the relative position with laser displacement sensors and is controlled by gas-jet thrusters not to collide the inner shell. Therefore the inner shell can be uninfluenced of the dynamic pressure and other aerodynamic disturbances ideally.

The outer shell made from CFRP(Carbon Fiber Reinforced Plastics) has rocket-like shape to reduce aerodynamic disturbance. Air drag is almost proportional to the square of the velocity and also proportional to the air density. In our estimation, to achieve 30 seconds duration, 100 N thrust is required. Therefore, the body has 16 of 50 N gas-jet thrusters. In Fig.2, Distribution of gas-jet thrusters is shown.

BOV's body can be split into a front body(airproof)

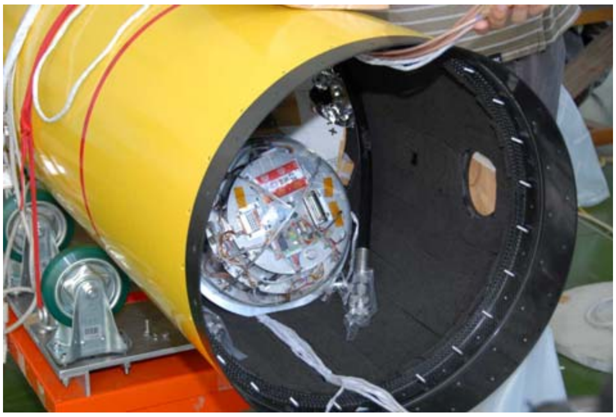

Figure 3: Micro gravity experimental capsule in the front body of BOV

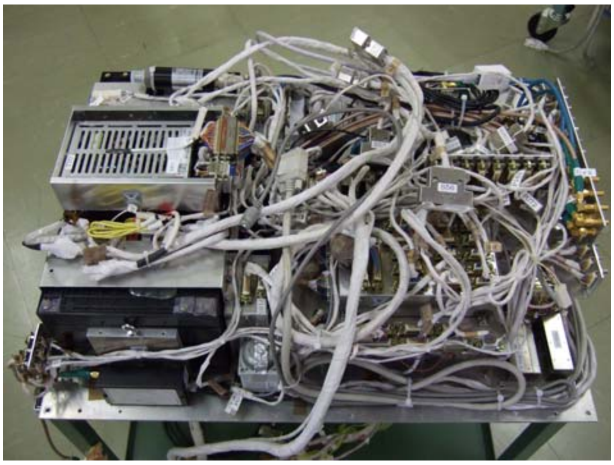

Figure 4: Electrical panel with some electrical devices

and a rear body. Below, the construction of the each part are related.

2.1 Front body

The front body of BOV has two fuction, a micro gravity experiment area and installing electrical equipments and tank. This part is designed to be airproof since BOV's equipments are consist of consumer components.

In the micro gravity experiment area, there is the sphere-shaped capsule(30cm diameter) in Fig.3. In the #2 experiment, a japanese sparckler is set inside to observe ignition in micro gravity environment. The clearance between the capsule and the body is ±10cm horizontal and ±20cm vertical. The middle of the front body, four laser displecement sensors are allocated to sense the relative distance between the capsule and the body.

In the downside of the front body, there are the electrical panel and the tank panel like Fig.4. In the electrical panel, a computer(CPU:SH-4, OS:RT-Linux)

Figure 5: Rear body of BOV

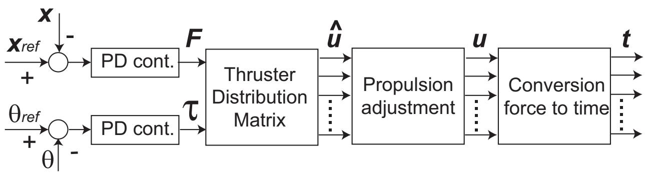

Figure 6: Block diagram of control system of BOV

managing all system, lithium-ion batteries(12V, 24V), motor driving units to drive wings and some sensors are set. This CPU gathers house keeping data and transmits telemetry to the ground base with recording to a storage device.

2.2 Rear body

In the rear body of BOV, there is mainly the parashute inside. After the micro gravity experiment, speed of BOV becomes supersonic. To reduce this speed, the pilot-chute is opened. In addition, main-chute is opened at 7.5km altitude for safety descent.

There are also four wings in the rear body in Fig.5. These wings has the function to stabilize the BOV's aerodynamic parameters.

3 Control System

As described in previous section, the most characteristic point of BOV is its double-shell structure. To realize this system, BOV has some guidance and control devices.

3.1 Translational Control

In the middle of BOV's body, there are four laser displacement sensors to measure clearance between the inner shell and the outer shell. This system estimates the center position of the inner shell by the Newton-Raphson method with four laser displacement sensors

Figure 7: Scenery of BOV's launch

on the assuming that the inner shell is sphere. Using this estimation, force commands are calculated in eqns.(1)-(3) with PD controller. K_*: control gains, F_*: force commands on each axe, $x_{ref}, y_{ref}, z_{ref}$: control references, $x_{est}, y_{est}, z_{est}$: the estimated center position of the inner shell. In eqns.(1)-(3), force commands are subtractive to move the body in relation to the inner shell relatively.

$$F_x = -K_{Px}(x_{ref} - x_{est}) - K_{Dx}(\dot{x}_{ref} - \dot{x}_{est}) \quad (1)$$
$$F_y = -K_{Py}(y_{ref} - y_{est}) - K_{Dy}(\dot{y}_{ref} - \dot{y}_{est}) \quad (2)$$
$$F_z = -K_{Pz}(z_{ref} - z_{est}) - K_{Dz}(\dot{z}_{ref} - \dot{z}_{est}) \quad (3)$$

3.2 Attitude Control

To realize the BOV's purpose, attitude control is also necessary to maintain stable micro gravity experiments. BOV has three fiber optical gyros to measure the body rates. In eqns.(4)-(6), torque commands are also calculated with PD controller. K_*: control gains, τ_*: torque commands, $\varphi_{est}, \theta_{est}, \psi_{est}$: Eular angles with body rate integration. φ expresses the axle around angle. In eqn.(4), the rolling angle is controlled by only D controller since the initial error angle is possible to exert a bad influence for that the balloon is rotated in the upper air.

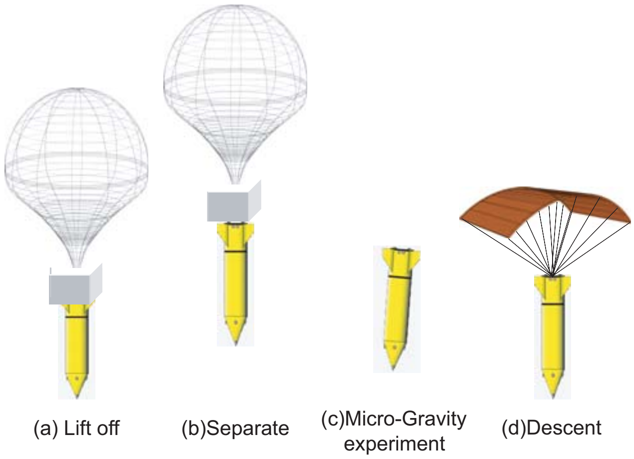

Figure 8: BOV's micro gravity experimental sequence

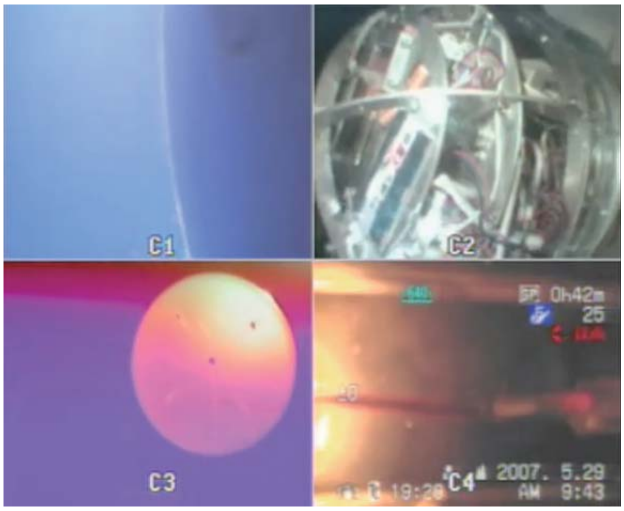

Figure 9: Beginning of Micro gravity experiment

$$\tau_\varphi = K_{D\varphi}(-\dot{\varphi}_{est}) \quad (4)$$
$$\tau_\theta = K_{P\theta}(-\theta_{est}) + K_{D\theta}(-\dot{\theta}_{est}) \quad (5)$$
$$\tau_\psi = K_{P\psi}(-\psi_{est}) + K_{D\psi}(-\dot{\psi}_{est}) \quad (6)$$

4 Micro Gravity Experiment

4.1 Experimental Sequence

In May 2007, BOV was launched at SANRIKU balloon center in Fig. 7. Fig.8 shows the experimental sequence of BOV. BOV was separated after the balloon arrives at 40km altitude. For 35 seconds the micro gravity experiment was carried out. This time, a Japanese sparkler was set to burn in the inner shell. The Japanese sparkler was ignited at the same moment with separation to observe ignition in micro gravity environment. After the experiment, the pilot-chute was opened for speed reduction. In addition, main-chute

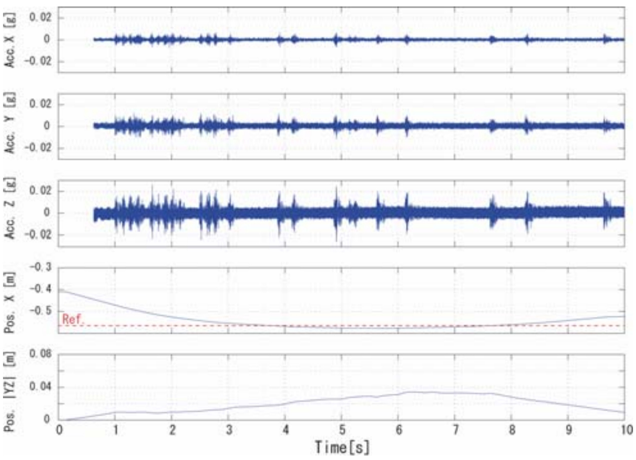

Figure 10: Experimental result of 0-10 seconds, acceleration and position of inner shell

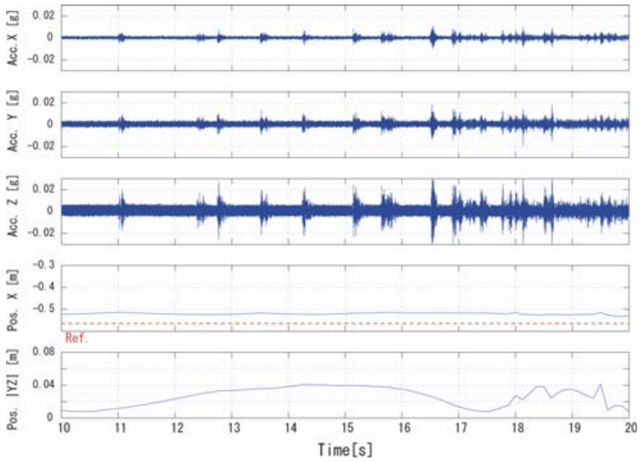

Figure 11: Experimental result of 10-20 seconds, acceleration and position of inner shell

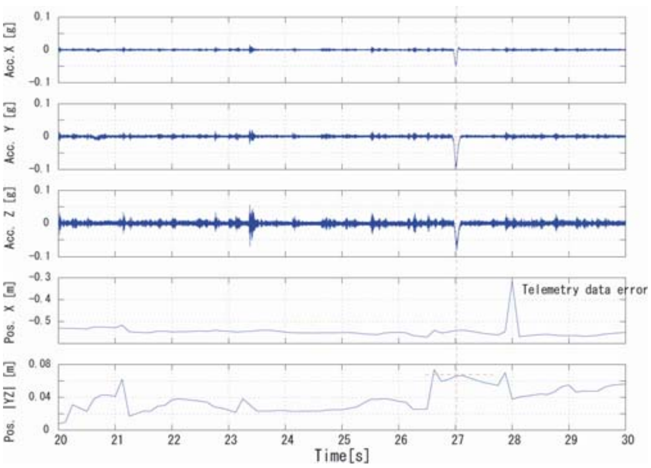

Figure 12: Experimental result of 20-30 seconds, acceleration and position of inner shell

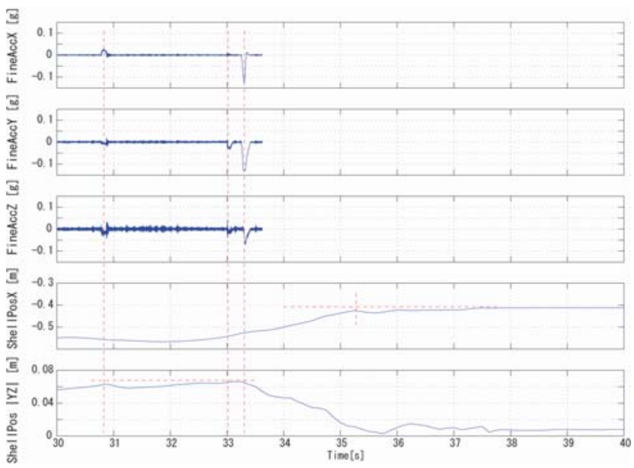

Figure 13: Experimental result of 30-40 seconds, acceleration and position of inner shell

was opened at 7.5km altitude for safety descent successfully.

4.2 Experimental Result

In the experiment we achieved about 30 seconds micro gravity with good quality. Fig.9 shows the beginning of the micro gravity experiment. The upper right figure shows the floating capsule successfully. The Japanese sparkler burned in first several seconds in the downward right figure in Fig.9, but after that the fire went out and the Japanese sparkler wasn't flash since there was no oxygen in the neighborhood for good micro gravity.

In figs.10-13, experimental results are shown, acceleration data on each axe and the position of the inner shell. From these experimental results, it can be seen that the inner shell didn't collide with the outer shell for 27 seconds and control system went well. But the acceleration data shows spike noise caused by gas jet thrusters. The inner shell is influenced by sonic wave of thrusters since BOV's body is airproof. Additionally, there is noise all the while in z axe especially. After the analysis, it is caused by 150[Hz] drive noise of a digital video.

Finally the inner shell and the BOV's body collided after 27 seconds. This is caused by rotation of the inner shell. It is proved from the video camera that the inner shell began to rotate when BOV was separated. Moreover, since the shape of the inner shell is oval, the inner shell collided earlier than presumption. But the almost all system is verified to propose the good micro gravity environment.

5 Conclusion

In this paper, new micro gravity experimental system is proposed. This system has double shell structure and the inner shell can fall freely. In the experiment, we realize good-quality micro gravity and realize to continue moderate micro gravity duration. This system is now improving and near future we can utilize BOV's system for moderate micro gravity duration with low-cost easily.

6 Acknowledgement

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