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Polar Patrol Balloon

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From late December of 1990 to early January of 1991, the National Institute of Polar Research, in collaboration with the Institute of Space and Astronautical Science, launched two large zero-pressure balloons from Syowa Station, which is the Japanese research base in Antarctica. The balloon launched on December 25 returned near Syowa Station after 15 days of flight, keeping a constant altitude of about 30 km. It finally accomplished almost a one and half circumpolar flight. The total flight duration was about 40 days. This article will describe the balloon system and the flight behavior of the balloon.

Introduction

THE Polar Patrol Balloon (PPB) project is a long-duration circumpolar flight in Antarctica. In the summer season the circumpolar wind is predominant and there is no sunset near the polar region in Antarctica. If we launch a large zero-pressure balloon under those specific conditions, we can expect that it will return very close to the launching site after a few weeks of flight, because of saving ballast consumption at sunset.[1]

Since 1984, the National Institute of Polar Research (NIPR) and the Institute of Space and Astronautical Science have developed ballooning technologies for the PPB program. In 1987 and 1990 three test flights were carried out at Syowa Station (69.0°S, 39.6°E) in Antarctica. These flights aimed at observing the atmospheric and radiation environment in the Antarctic stratosphere. Balloon control instruments such as an automatic ballast control system were also tested by the flights.

At the last experiment in January 1990, the PPB almost completed a circumpolar flight (about $\frac{7}{8}$ of the circle) and followed the predicted trajectory that had been calculated using statistical wind profiles in the Antarctic stratosphere.[2]

Based on the results of the successful test flights, the PPB program for the purpose of scientific observations was planned as one of the NIPRs main research projects in the Antarctic region and started in 1990 on a 3-yr plan.[3] In 1990 two balloons (PPB-1 and PPB-2) were launched by the members of the 32nd Japanese Research Expedition. Figure 1 shows the preparation work before launching at Syowa Station. The first balloon that was launched on December 25, 1990 returned near the launching site after 15 days of flight (on January 9, 1991). Then it continued to fly and finally accomplished almost a one and a half circumpolar flight. The total flight duration was prolonged to no less than 40 days.

The second balloon was launched on January 5, 1991. It traveled about halfway around the circumpolar trajectory by January 12, 1991. The flight direction, however, reversed, due to both the descent of flight altitude caused by a balloon problem and a seasonal change of wind direction.

Those PPBs carried scientific instruments for the observations of the auroral x ray and of electric and magnetic fields. The observation systems worked well and a lot of beneficial scientific data was obtained.[4]

Balloon System

The balloon sizes, the payload weights, and the ceiling altitude are listed in Table 1. The initial ceiling altitude was

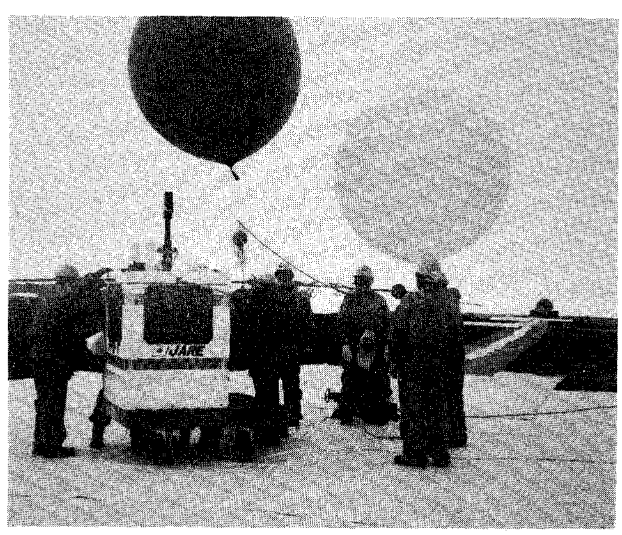

Fig. 1 Preparation work of balloon launching at Syowa Station.

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Table 1 Specification of two PPBs launched at Syowa Station in Antarctica

	PPB-1	PPB-2
Launching date	08:25UT,[a] December 25, 1990	18:55UT,[a] January 5, 1991
Balloon size	25,000 m^3	32,000 m^3
Balloon weight	107 kg	127 kg
Payload weight	116 kg	200 kg
Ballast weight	150 kg	152 kg
Ceiling altitude	30 km	30 km

[a]UT = Universal time.

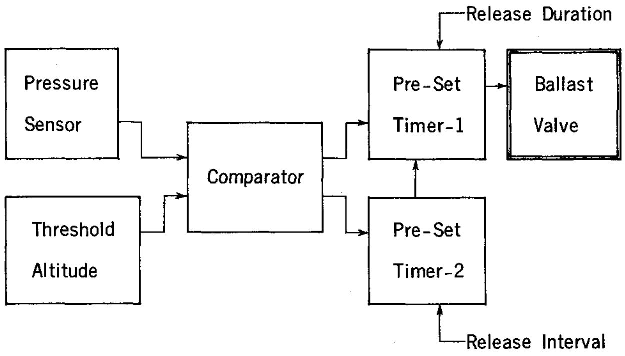

Fig. 2 Automatic ballast control system.

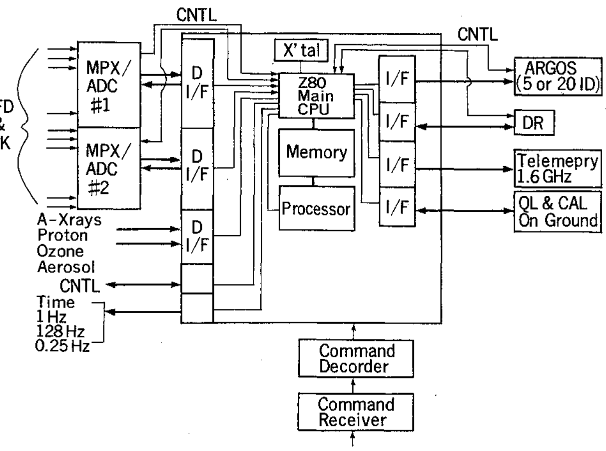

Fig. 3 Data handling system using multi-ID ARGOS system.

determined by considering the circumpolar wind condition and the requirement of scientific observations, especially the x-ray observation. For the auroral x-ray observation a higher altitude of more than 30 km is needed.

Ballast weight was decided by estimating the average consumption to be about 2%/day, and the flight duration about 15–25 days. Then the amount of ballast becomes almost 30–40% of the gross weight.

During the long-duration flight, most of the trajectory of a PPB is out of receiving range of the ground station. Therefore, a ballast control system for keeping constant ceiling altitude must work automatically without using a tele-command. Figure 2 shows the control system for the PPB. The descent of a balloon is detected by a precision pressure sensor. When the output of the sensor becomes less than the threshold level, the control system drops a certain amount of ballast at every preset interval until the balloon rises up over the threshold level again. According to the theoretical study and the results of test flights, we set the amount of ballast released each time at 2 kg and the interval at 300 s.

The threshold level is adjusted at 2 km below the initial ceiling altitude. This rather narrow range was selected from the requirement of x-ray observation. If this level is set lower, the atmospheric temperature increases 1.6°C/km, and we can save ballast consumption. The exact time when a unit of ballast was dropped was sent by telemetry.

Flight data of balloon control and scientific observations was sent to the ground station using the satellite link communication system, ARGOS. This satellite system is a very convenient tool, not only for positioning of balloons, but also for the transmission of small amounts of data. In order to improve the capacity of data transmission, we have developed a so-called multi-ID ARGOS system. This system has 20 different indentification numbers, and sends a data with a certain identification number changed at every transmission cycle. The system can simulate 20 independent ARGOS systems, and so data transmission capacity increases 20 times that of ordinary ARGOS. The system diagram of this multi-ID ARGOS is shown in Fig. 3.

Flight Behavior of PPB-1

Figure 4 shows the trajectory of the PPB-1. At the first stage of the flight, PPB-1 flew to the inside of Antarctica. At that time, the circular wind was not as strong around that area as usual. Six days later (December 31) the balloon began to follow a normal circumpolar trajectory. Compared with the actual balloon trajectory and the trajectory calculated from the wind data at the height of 15 hPs, two trajectories were quite coincident as shown in Fig. 5. This wind data was obtained by the objective analysis of the Japan Meteorological Agency.

The PPB-1 accomplished perfect circumpolar flight in 15 days, and passed about 200 km N of Syowa Station on January 9. It still continued to fly, and on January 11 consumed all the ballast. Then the balloon gradually started to descend, and on January 19 it reached the region where the wind direction was opposite. That point was on a one and a half circumpolar flight course.

As described in the previous section, when the balloon altitude falls below the threshold level, the automatic ballast control system drops ballast and the balloon rises again. Thus the balloon altitude repeats the periodical change between theoretical ceiling altitude and preset threshold altitude. The transition of the altitude from December 25 to 31 is shown in Fig. 6. The timing and weight of ballast dropping are shown on the figure by the arrow marks. Periodic changes of the balloon altitude basically correspond to the daily variation of sunshine, and minor differences may be caused by the radiation condition of the ground such as snowy field, sea, or in case of the existence of cloud down the balloon.

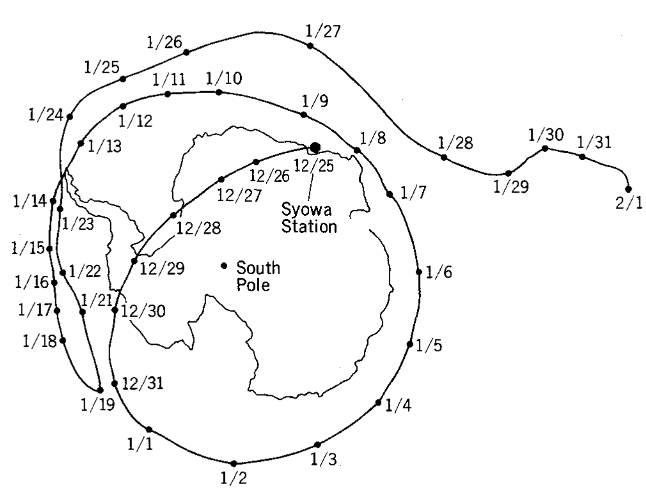

Fig. 4 Flight trajectory of PPB-1.

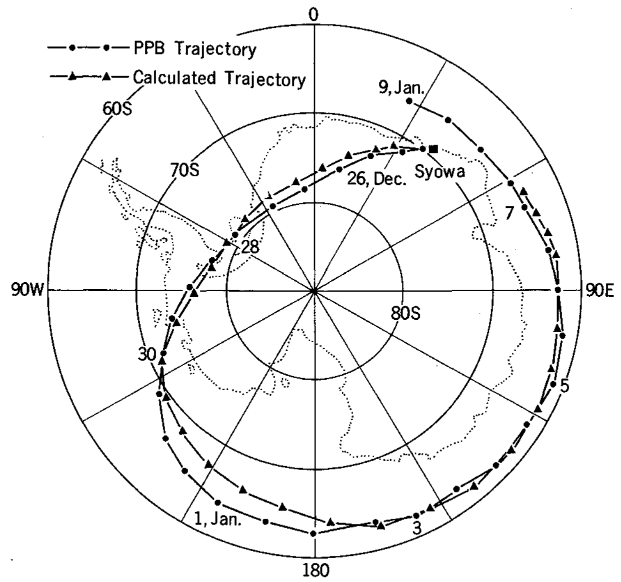

Fig. 5 Comparison of the actual trajectory and the calculated trajectory.

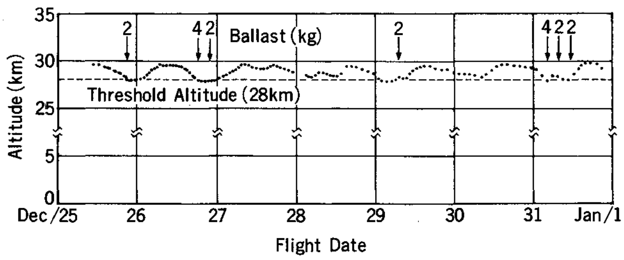

Fig. 6 Transition of the ceiling altitude of PPB-1.

This figure shows the excellent operation of the automatic ballast control system. The control system started to drop ballast just when the balloon altitude fell below the threshold level. Then the balloon began to rise with reasonable slow speed. It did not expend excessive ballast.

Ballast consumption depends on the radiation condition from the sun. Even though there are little or no nighttime hours in Antarctica in the summer season, the slight difference of sunset conditions, such as the difference between sunset at the ground or sunset at balloon altitude, have a great influence on ballast consumption. The latitude of Syowa Station is 69°S. This latitude is nearly on the borderline where the sunset may or may not occur during this season. Therefore, the deviation of the circular trajectory from this latitude closely affects the solar radiation condition.

By the theoretical analysis of ballast consumption—in case of sunset only at the ground—the consumption is estimated at 2 or 3% by the effect of vanishment of Albedo, and 5 to 7% in case of sunset both at the ground and at balloon altitude.

Figure 7 shows the actual relationship between ballast consumption and solar radiation conditions. The lateral axis is the flight date, and the vertical axis means ballast consumption/day as a ratio of gross buoyancy. The dark-time intervals at the balloon altitude and the ground are also shown on the figure.

From January 25 to 31 the ballast consumption was almost zero because the balloon passed through the high-latitude region and there was no sunset. From December 31 to January 2, ballast consumption gradually increased 3 or 4%, because the sunset at the ground appeared while there was still no sunset at the balloon altitude. After that the balloon latitude slightly decreased and sunset occurred both on the ground

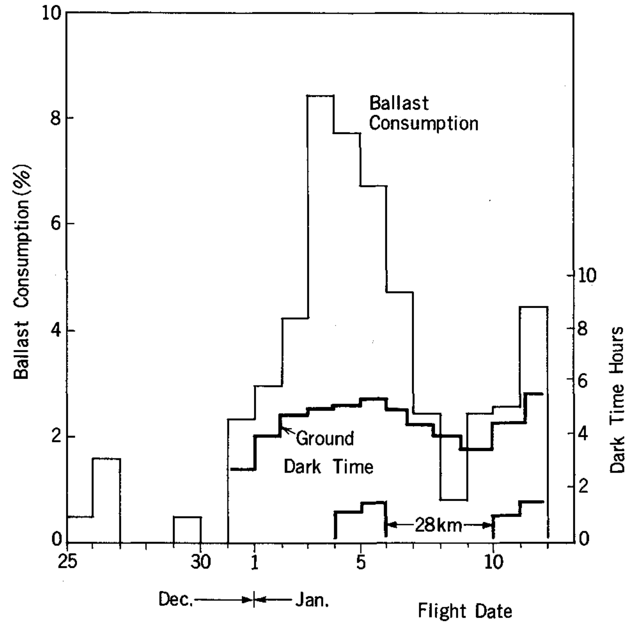

Fig. 7 Ballast consumption of PPB-1.

and at the balloon altitude. Therefore, on January 3 and 4, the ballast consumption reached the maximum level of 7 or 8%. After January 6 the balloon shifted to a higher latitude point again and ballast consumption reduced. From January 9, the latitude decreased, however, on January 11 all the ballast was consumed and the balloon gradually started to descend.

Discussions and Conclusions

The Polar Patrol Balloon launched on December 25 at Syowa Station accomplished complete circumpolar flight over Antarctica. The balloon system and flight behavior were explained in detail. Through this PPB experiment, we obtained a lot of good data on the relation between the ballast consumption and the solar radiation condition. This data is essential and useful for a long-duration flight (more than 20 days) in Antarctica. Based on the success of this flight we expect to be able to carry out PPB flights with high reliability every summer season in the polar region.

As for the launching date, it will be more appropriate to launch PPBs some days earlier because the circumpolar wind usually becomes predominant from early December, and the wind can be expected to remain until the end of the circumpolar flights. However, the launching date strictly depends on the operation program of the Japanese Research Expedition. We cannot start preparing for balloon experiments until all the balloon equipment has been unloaded. Therefore, December 25 is the most probable early launching schedule.

Compared with a usual balloon campaign at our regular balloon facility, there are some difficulties in launching balloons in Antarctica. For example, there is the short preparation time, the small number of launching staff, and severe weather conditions. In spite of these difficulties, it is necessary to make every effort to improve the PPB project, because there are many research items peculiar to the Antarctica in many fields of sciences, such as electric and magnetic fields, auroral x ray, ozone, and NOx observations. PPB will become a useful system for further studies of rare astronomical events, such as isotope separation of cosmic rays, gamma ray bursts, and low-energy antiparticles in cosmic rays.

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