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Scientific paper

Feasibility study on scientific balloon experiment at Ny-Ålesund

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Abstract: This paper deals with the possibility of scientific ballooning in the Arctic (at Ny-Ålesund). This study is based on balloon experiments carried out at Syowa Station, Antarctica, from 1996 through 1999. Under typical flight conditions, such as five-hour flight duration at 30 km altitude, balloon trajectory simulation at Ny-Ålesund demonstrated the flight range within 150 km in June through August, and large possibility of payload recovery. A new type of super-pressure balloon developed by a Japanese balloon group, which promises a long duration flight at constant altitude, will be a useful platform. New onboard systems and ground facilities developed for the preceding balloon experiment in the Antarctic will be applicable to scientific observations over Arctic regions.

1. Introduction

Polar regions are interesting places to study atmospheric chemistry and physics in the stratosphere, and upper atmospheric physics. Scientific balloons are one of the most powerful and economical tools for those studies. Ballooning in those areas, however, encounters many difficulties, such as low temperature, insufficient facilities and logistics, and lack of skilled manpower.

One of the important subjects is meteorological conditions for a balloon experiment, especially surface wind speed, wind speed and direction in the troposphere and the stratosphere. These conditions directly affect observation time and the possibility of payload recovery. Other research subjects are onboard equipment and ground facilities. In the stratospheric air sampling project, National Institute of Polar Research (NIPR) has experienced ballooning at Syowa Station, Antarctica, in cooperation with the ballooning group of the Institute of Space and Astronautical Science (ISAS). The project included the simulation and analysis of flight trajectories, development of launching and tracking instrumentation, and recovery operation on sea ice and on the sea (Honda *et al*., 1999a, b; Yajima *et al*., 1999a; Aoki *et al*., 1999). Technological achievements in the champaign are quite helpful when we consider the applicability of scientific experiments at the Arctic regions.

Scientific observation by a long duration balloon flight is one of the most effective research methods, comparing favorably with satellite observations. A super-pressure balloon, which has been developed by the ISAS balloon group (Yajima *et al*., 1999b; Yajima, 2000), is one of the most promising candidates. More than one-month flight duration is possible for a super-pressure balloon, whereas a conventional zero-pressure balloon can fly for only one week or less.

In this paper, the meteorological feasibility of a balloon experiment at Ny-Ålesund is discussed first. Then the new ballooning technology and the technological achievements in Antarctica, which are applicable to the Arctic balloon campaign, are explained.

2. Meteorological feasibility at Ny-Ålesund

From the viewpoint of ballooning, meteorological feasibility was studied. There are two important factors in ballooning operations: balloon launching and payload recovery. The former largely depends on the surface wind speed; the latter is affected by the wind speed and direction in the troposphere and stratosphere. Here, possibilities of payload recovery by trajectory simulation were first examined using the daily wind profiles over Ny-Ålesund in 1995. This was the same method that had been used in the Antarctic (Honda *et al.*, 1996a). The accuracy of the simulation was confirmed to be within 1 km through actual flights and recovery operations at Syowa Station, Antarctica (Honda *et al.*, 1996b). The capability of balloon launching was also estimated by considering daily surface wind speed data. For safety of balloon launching operations, wind speed of 3 m/s or less is suitable.

2.1. Trajectory simulation

A time-altitude profile during a five-hour observation duration at 30 km altitude was assumed, as shown in Fig. 1. The maximum altitude of the meteorological observation is often less than 28 km because the rubber balloon bursts, especially from January through March and November through December. Such profiles were not used in the trajectory calculation here. When the balloon burst altitude was between 28 km and 30 km, the wind speed and direction up to 30 km were considered to be the same as those at the balloon burst altitude.

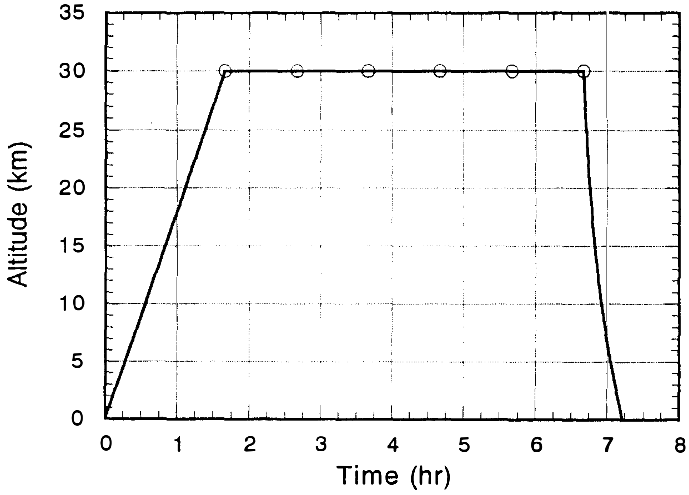

Fig. 1. Time-altitude profile used in trajectory calculation. Small circles indicate one-hour intervals after a ceiling altitude is reached.

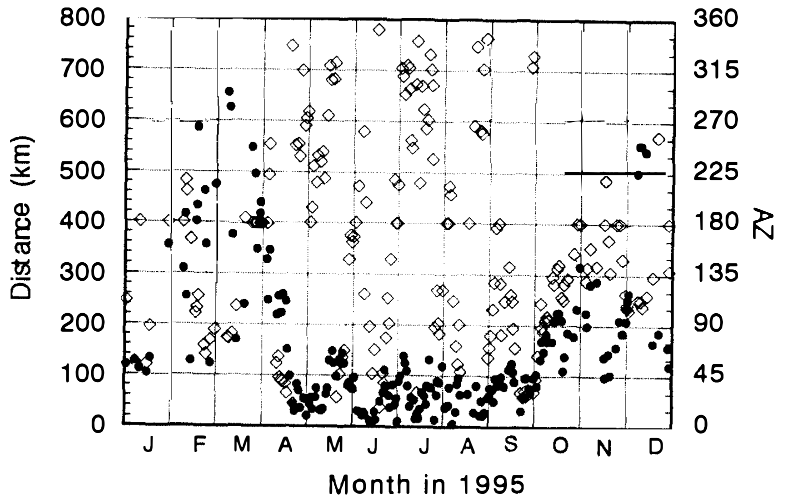

Fig. 2. Simulated landing point distances (black circles) and directions (white boxes) distribution from the launch pad in Ny-Ålesund, 1995. AZ indicates the direction, 0, 90 and 180 are north, east and south, respectively.

Balloon flight trajectories were calculated under the conditions described above. The distribution of the landing point distance and direction from Ny-Ålesund estimated for 1995 is shown in Fig. 2. The distance changes gradually throughout the year, being longer in winter and shorter in summer. The direction changes largely by two-month cycle in summer and is rather stable in winter. Westward (AZ around 270) is preferable for the payload recovery because of the open sea, which ensures that telemetered data can be received as low as sea level at the ground station without obstruction by mountains.

Figure 3 presents the results of the calculated distances between the estimated landing points and Ny-Ålesund. "No data" shown in the figure means that the calculation was not performed because no meteorological data were available or the balloon burst altitude was lower than 28 km. In the discussion below, the case of "no data" is excluded.

The landing points are categorized into five ranges, from one less than 50 km (expressed $<$ 50 km in the figure) to one not less than 200 km ($\geqq$200 km) in 50 km steps as shown in Fig. 3. All payloads are expected to land within 150 km of the launch pad from May through September. When the distance is limited to within 100 km for easier recovery operation, the occurrence ranges from 68% in May to 95% in August. In other months most landing points were farther than 150 km, and there will be little chance for recovery at short range.

Simulated trajectories for June, 1995, are plotted on the map as shown in Fig. 4. Most are within the 100-km circle as shown in Fig. 3. They are distributed on the sea and also on land. Landing on the island, however, has to be avoided for safety reasons and easier recovery operation. At Ny-Ålesund the recovery operation on the mountainside is more difficult than that on the sea because of the steep ice slopes. The balloon flight course can easily be controlled onto the sea by changing altitude by venting helium gas from the balloon or ballasting. According to analysis of the landing point distribution in the Antarctic work, the landing point distance and direction from the launching station varied only slightly day by day, and its tendency could be predicted easily (Honda *et al*., 1999b).

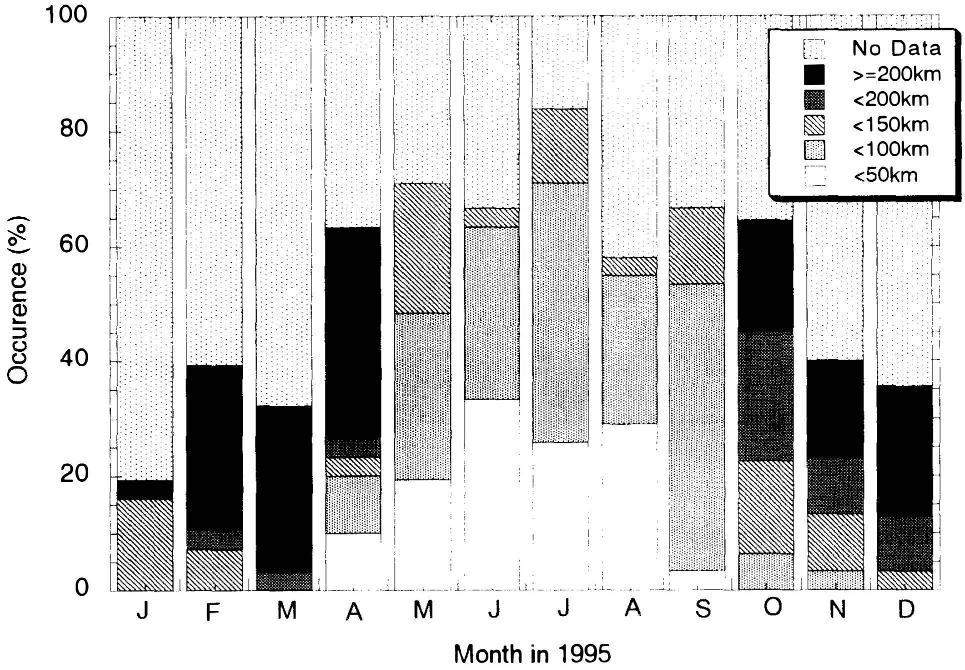

Fig. 3. Occurrence of simulated landing point distances, as shown in Fig. 2, classified into six categories. < 100 km includes landing point distances of at least 50 km but less than 100 km, for example. "No data" means that the calculation was not performed because no meteorological data were available or the balloon burst altitude was lower than 28 km.

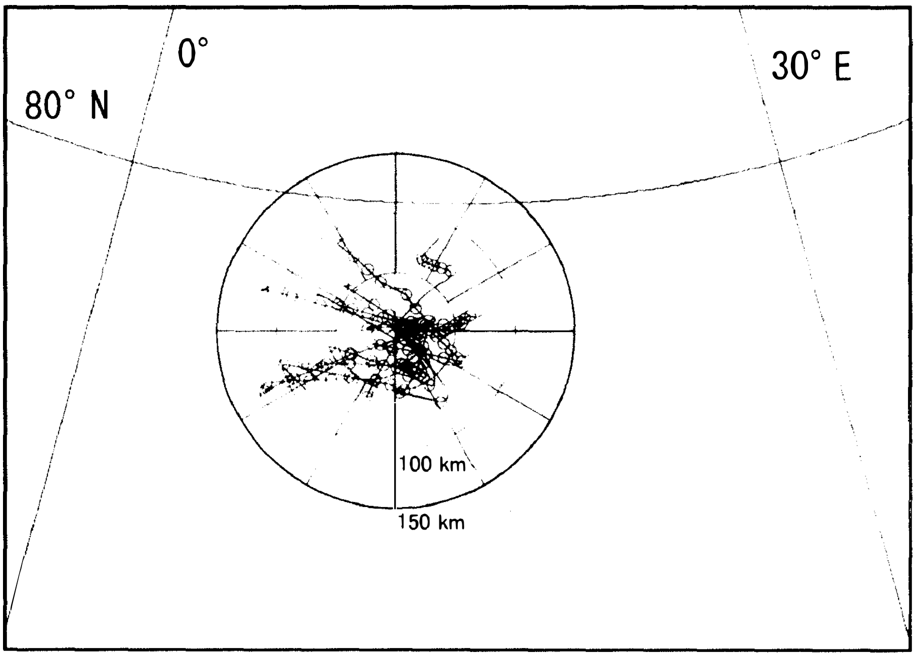

Fig. 4. Trajectories of June 1995 superimposed on a map of Ny-Ålesund. The three large circles indicate the distance from the launch pad, 50 km, 100 km and 150 km, respectively. Small circles on each trajectory present the same time and altitude as in Fig. 1.

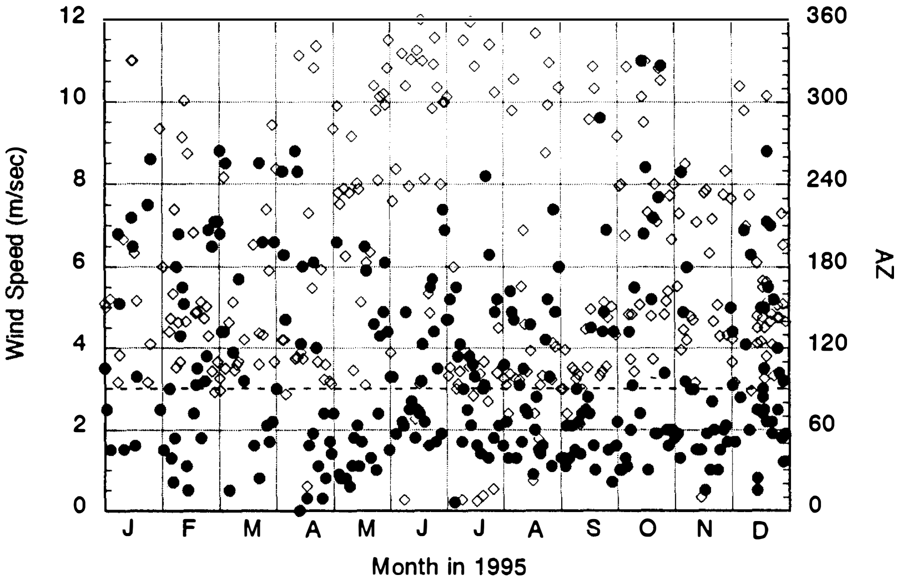

Fig. 5. Surface wind speed (black circles) and direction (white boxes) distribution at Ny-Ålesund in 1995. The broken line of 3 m/s indicates the maximum wind speed for safe launching of large balloons.

2.2. Surface wind

Another important factor for launching balloons, ground wind speed on the launching day, is plotted in Fig. 5, also for 1995. The broken line of 3 m/s indicates the maximum speed for safe launching operations of large balloons. The percentages of days having wind speed less than 3 m/s are 65%, 56%, 35%, 52% and 72% for May, June, July, August and September, respectively. The launching opportunities are not so limited compared to the situation in Japan. The wind direction at the surface is generally not a critical factor as long as the launch pad is open and no tall building or other obstacle nearby.

3. Ballooning facilities and instrumentation

Ballooning facilities and instrumentation, that are needed including balloon, a gas inflation system, a launch vehicle, an auto-track and telecommand system, and recovery equipment are given below. Some of these were designed for and used in the Antarctic from 1996 through 1999 (Honda *et al*., 1999c, 2000; Izutsu *et al*., 1999), and are equally useful for the Arctic balloon experiment.

3.1. Super-pressure balloon

The Japanese ballooning group has developed a new type of super-pressure balloon (Yajima *et al*., 1999a; Yajima, 2000), for a long duration flight, longer than one month, at constant altitude. Figure 6 shows a 3000 m^3 super-pressure balloon in an indoor inflation test. The balloon made a successful flight on 15 May 1999 and became the first super-pressure balloon with a heavy payload in the world. Development of a larger balloon is now in progress.

The super-pressure balloon can fly on a circumpolar orbit when it is launched in a

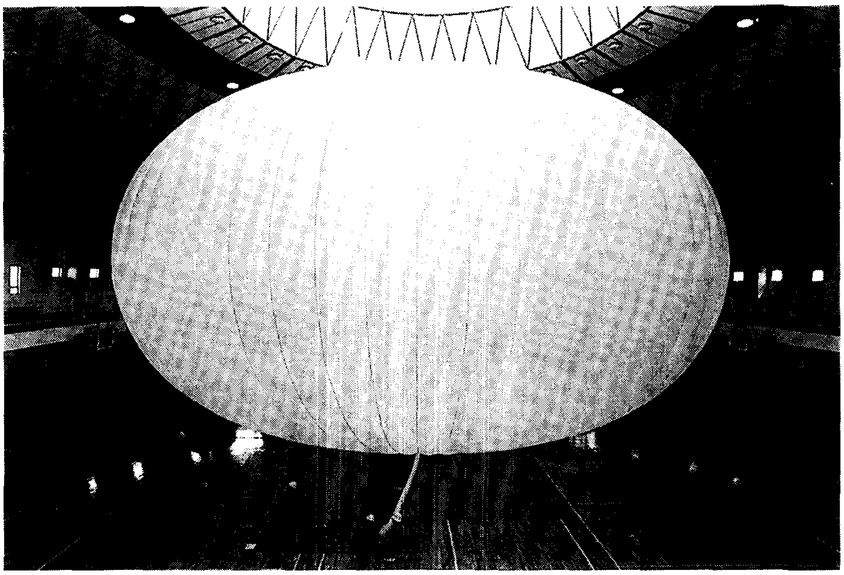

Fig. 6. A 3000 m^3 super-pressure balloon under an indoor inflation test.

polar vortex. It allows a scientific instrument to observe upper atmosphere by solar occultation method repeatedly and radiation from the earth surface continuously, for instance.

3.2. Power system

A large solar power generation system is under preparation for long duration flight using the super-pressure balloon. The system is made of several solar panels which can expand. When a balloon reaches its ceiling altitude, the stored panels are deployed downward. The system can follow the sun in order to achieve the maximum power generation efficiency.

3.3. Telecommunications system

There are two telecommunications systems; an ordinary one that was developed especially to be as simple as possible and a new one aimed at long duration flight. The former was used in the Antarctic campaign and functioned as expected (Honda *et al.*, 1999a; Yajima *et al.*, 1999a; Aoki *et al.*, 1999). The latter is under development.

A handy telemetry and telecommand system was designed for the Antarctic. The system consisted of a telemetry and a telecommand antenna, a biaxial rotator, an L band receiver, a telemetry demodulator, a transmitter and PCs. As the tracking range was limited within 150 km due to the recovery operation requirement in the Antarctic, a 15-element Yagi antenna was sufficient to receive the telemetry signal. The PC calculated the antenna attitude to direct it to the balloon using GPS data transmitted from the balloon. This method drastically simplified the auto-tracking system. The system required only a few staff members for one day to set up and test the antenna on a roof and the communications system in a room. For balloon experiments at Ny-Ålesund in the future, the receiving station may be set up on a mountain site for long range and wide coverage.

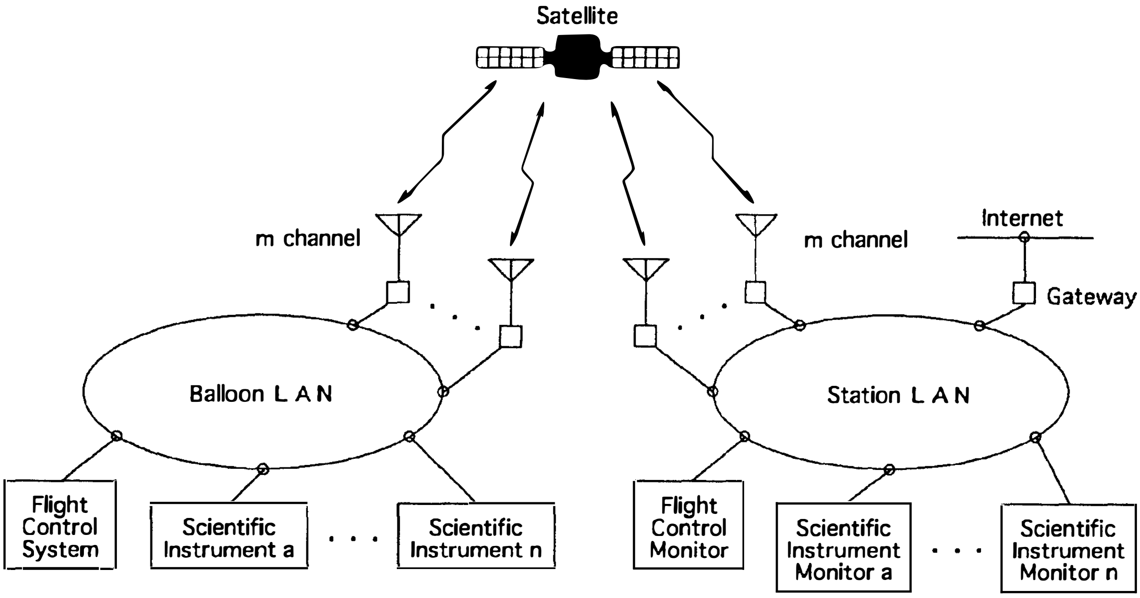

Fig. 7. Schematic diagram of a network configuration onboard the balloon, a telecommunications system, a ground station and Internet connections.

The new onboard system utilizes multiple satellite telephones as the communications system to be free from coverage of ground stations, to increase reliability and to improve total transmission capacity. This system can provide bidirectional communications, and onboard instruments can be manipulated interactively from the ground. A schematic of the concept of the new telecommunications system is shown in Fig. 7.

3.4. Network data transfer

Scientists in a remote office can access the onboard instruments and check the status in real time via the Internet, as has been demonstrated in the Antarctic (Honda *et al.*, 1999a, 2000). In Antarctica in 1998, all of the telemetry data were transferred to NIPR in Tokyo in real time through the computer network at Syowa Station via INMARSAT. This system was a powerful tool in both ballooning and the air sampling operation in the sense that engineers and scientists in Japan could monitor the status and data from the onboard systems in real time from the preparation stage of the payload instrument. They could also send instructions and advice to people at Syowa Station.

3.5. Launching facilities

A gas inflation system was designed, for the Antarctic work, to measure gas pressure and temperature precisely in order to determine the lift of the balloon, and to permit manual control of inflation speed. It could connect more than 100 helium gas bottles of 47 liters by volume, and has the capacity to inflate a balloon of 800 kg lift force within 30 min. A launcher for a small payload was also developed. It was capable of 80 kg lift force for a plastic balloon. Another launcher for a large balloon was installed in the previous balloon campaign called the Polar Patrol Balloon (PPB) (Ejiri *et al.*, 1993).

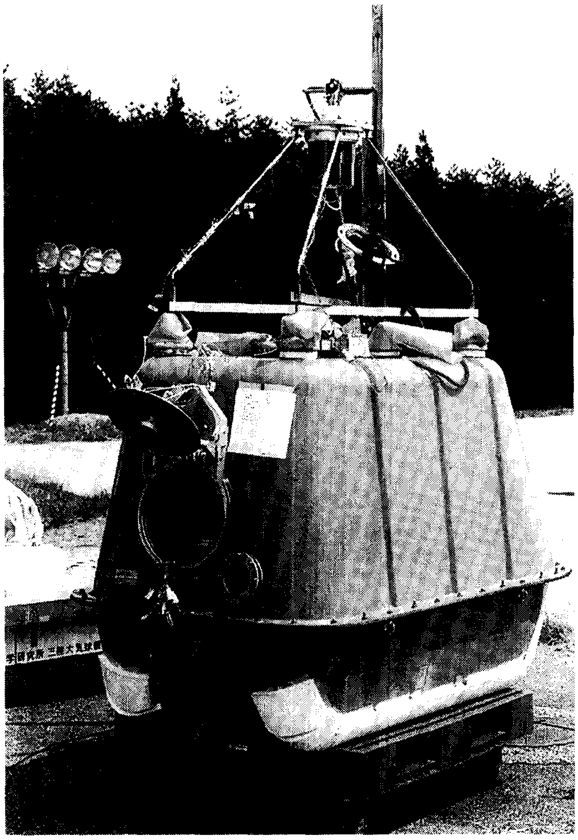

Fig. 8. A waterproof gondola in use.

3.6. Recovery system

In order to recover a payload, its exact positioning during flight and after landing is required. The former could be determined by transmitting onboard GPS data to the ground station, and the latter by continuous transmission of a beacon signal for direction finding. Since all payloads are landed on the sea in balloon experiments in Japan, they are recovered using a ship in cooperation with a helicopter. When a helicopter is used and the GPS data are transferred normally, no extra search time is required to find the payload compared to the conventional recovery operation only by a ship.

The Japanese ballooning group has already developed a multipurpose waterproof gondola made of FRP (Fiber Reinforced Plastic) (Akiyama *et al*., 1992), which has a wide window allowing an optical instrument to observe the target without obscuration. It can house an instrument as large as 1.0 mW×0.6 mD×1.0 mH (see Fig. 8). It is already operational.

4. Conclusions

Scientific balloons are powerful platforms for scientific research in polar regions. Long duration flights are one of the candidates for future international collaborative scientific activities. The authors hope that the potential and merits of balloons will be realized in science in the Arctic using their new balloon technology as well as facilities developed for ballooning in Antarctica.

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