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TEN YEARS OF SCIENTIFIC BALLOONING ACTIVITIES IN JAPAN (1966 - 1975)

気球観測事業 10 年の歩み（1966 ~ 1975）

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Ten Years of Scientific Ballooning Activities in Japan (1966 - 1975)

1. INTRODUCTION

The year 1975 marks the end of the first decade of scientific ballooning activities in Japan, a task undertaken by the Institute of Space and Aeronautical Science, the University of Tokyo. During these ten years the Sanriku Balloon Center was established as a permanent test site. The size of balloons also increased and by 1973 a balloon with a capacity of 200,000 m^3 was launched successfully. In all some 228 balloon launches took place and good results in terms of scientific observation were obtained so that today Japan still continues to lead the way in balloon sounding.

The results of ballooning activities in Japan are published each year in the Proceedings of the Scientific Balloon Symposium and in the Bulletin of the Institute of Space and Aeronautical Science, the University of Tokyo, Special Edition on Scientific Balloons. In the present paper a summary of the policies and results that have emerged during the past ten years and some consideration on future developments are presented.

2. PROGRESS OF BALLOON OBSERVATION IN JAPAN

The progress made since the establishment of the Balloon Division at the Institute of Space and Aeronautical Science in 1966 was reported by Hanabusa et al (1971). Here, a summary of it will be given.

The first plastic balloons in Japan were launched in 1953 for the purpose of observing cosmic radiation using nuclear emulsions. It was at that time when such emulsions were being studied at some Japanese universities and were successfully used in the detection of π-μ mesons in other countries. Nuclear emulsions were exposed in the upper atmosphere where the intensity of cosmic radiation was high, and the plates were subsequently recovered. These nuclear plates were the most suitable device for experiments of this kind.

Researchers throughout Japan had concentrated on the study and in 1950 rubber balloons equipped with nuclear plates were launched at the Tateno Aerological Observatory, Ibaraki Prefecture. The balloon had a diameter of two meters and ascended to an altitude of approximately 25 km whereupon it ruptured and the payload descended to earth by parachute. Efforts were also made to prolong the period of observation in the upper atmosphere by attaching two or three balloons to each load. However, the load efficiency was poor and it was found difficult to overcome the disadvantages of the existing rubber balloons with which only a short period of time was available for observation.

At the same time as these experiments were being carried out, related work involving plastic balloons began in laboratories in the United States and Great Britain and these studies have continued up to the present.

While, in 1953, polyethylene films were being developed in Japan, production and launching of plastic balloons was carried out by cosmic-ray researchers, principally from the University of Kobe. When considered in the light of current developments, the early polyethylene film was very inferior and there were many setbacks, but fortunately one of the 500-m^3 balloons was successful in ascending to 20 km and went into level flight for several hours. This fact was clearly demonstrated by the radiosonde which had been incorporated as a part of the payload. Thus, balloon observations using nuclear emulsions were carried out over longer periods of time than had been possible in the past.

In the following year balloon observations were made by a group of workers based at the Rikkyo University. Twenty-three plastic balloons were launched.

An event which deserves mention is the establishment in 1956 of the Cosmic Radiation Laboratory at the Institute for Nuclear Study, the University of Tokyo as a joint center for high-energy cosmic radiation research using emulsion chambers. Eight balloons equipped with 17 emulsion chambers were launched from Kobe and Shizuoka and the payloads were subsequently recovered (Minakawa et al, 1959).

While the development of cosmic radiation research was gradual, the significance of the utilization of balloons in this work was considerable and it also meant that balloon observations in Japan which had been slow in starting began to approach the international level.

However, the success of the work rather ironically gave rise to a new problem. This was how balloon experiments in Japan should develop in the future.

The designs of 1956 had been achieved on the basis of the knowledge and experience that had been gained by the workers up to that point. For this reason if no other, it was impossible for these workers to design models on an even larger scale using the system as it was at that time.

To increase the load capacity and to produce balloons that would have a high efficiency and be very stable, it was necessary to provide a suitable system of development. After some debate among the people concerned a system of balloon research was established, and if high-efficiency balloons could be produced, then there would certainly be benefits for space observation as a whole as well as for cosmic radiation research which had been to the fore up to that time. It was probably as a result of this work that space science which has become a speciality here in Japan came into being at all. That this state of affairs may come about was, of course, one of the conclusions reached by the workers in the field at that time.

The events that followed are well known. Discussions were held in Japan and a little later in the United States, France and India. What was different in Japan was that in those other countries the test site for the system was planned after only a year or two. In the United States, the National Scientific Balloon Facility (Palestine, Texas) was established within NCAR; in France the Erusldeau (phonetic) balloon site was set up under CNRS and in India the Hyderabad Balloon Facility was completed at the Tata Institute of Fundamental Research. Much study was carried out via these balloon centers, enabling plastic balloons and observation techniques to advance by leaps and bounds.

However, here in Japan several years were needed to set up balloon operations.

During the progress of these discussions, the Japanese rocket group was considering the IGY and their endeavors were focused on the rockoon system in which a rocket is fired off from a balloon. It was also at that time that fundamental research into balloons was started and then the rocket program was wound up as ground launching became safer. Details of the progress made in this field were reported by Fukuda et al (1960), Hirao and Okamoto (1960) and Hirao et al (1962).

Thus, since it was clear that the setting up of a new balloon system would require a considerable period of time, two interim plans were made. The first was to investigate launching methods for balloons that were to carry very heavy payloads, and it was decided that the work would be undertaken principally by the group centered at the University of Kobe. The other plan called for an investigation of the design and fabrication of balloons by the Institute for Nuclear Study, and this resulted in the production of 50 balloons with volumes ranging from 100 to 3,000 m^3. It was from the basis of the research and investigations made during this period that the balloons of today were developed. An investigation was also carried out using these prototype balloons to try to find a system by which the balloons could be held in level flight for longer periods. It was at this stage that the concept of the cycling balloon was born, and test flights with this system were carried out (Fujimoto et al, 1962; Nishimura, 1966; Niu, 1966).

The whole system of space science development in Japan was being discussed at that time and this resulted in a plan to establish a space science research institute. The scope of observations from rockets was increased and a joint research institute was set up to carry out fundamental studies for the development of rockets and observations which depended principally on existing research work.

A balloon specialist group was also set up in order to participate in the research projects that were being undertaken by workers from all over Japan in which balloon observations were important, and this group also included those who were interested in carrying out observations from large-capacity balloons.

The concept of a space science research institute led on to the establishment of the Institute of Space and Aeronautical Science in 1964, but this does not give a particularly clear perspective of the setting up of bodies closely related to the development of balloons.

Results concerning space observations that had been made from balloons were then published in other countries, where no such fundamental studies had been undertaken, and the workers in Japan began to feel somewhat apprehensive. This, of course, had an influence on the state of affairs, and in 1965 the Balloon Committee was set up under the chairmanship of Professor Kawamura at the Institute of Space and Aeronautical Science. The initial objectives of the committee were to investigate the details of matters related to balloons which would have to be dealt with in the future by the Institute of Space and Aeronautical Science and to investigate the role of the Balloon Specialist Group in the future plans. The committee also undertook the arrangement of the first scientific balloon symposium and obtained the opinions of interested workers from all over Japan.

During the ten-year period from the first launching of a plastic balloon in Japan, the field of interest in balloon observation has widened considerably and an enthusiastic discussion ensued at the first symposium which lasted for three days and which was attended by about one hundred interested parties and covered balloon technology and observations made in such fields as astronomy, geophysics, and cosmic radiation (Kawamura, 1966).

The plans and expectations of the various people with respect to the development of larger light-weight high-efficiency balloons, the requirements of the equipment that would make up the systems and the significance of balloon observation were discussed and formed the closing notes of the symposium.

In April of 1966, the Balloon Division was set up at the Institute of Space and Aeronautical Science and the impetus behind this establishment increased. According to the records some of the plans that were dealt with by the Balloon Division are as follows:

(1) Development and standardization of balloons. The development of balloons was to start at the 5,000-m^3 level, with production of larger ones each year until they reached a volume of 100,000 m^3 after a few years. Lighter balloons were also to be designed and fabricated for observations at even higher altitudes.

(2) Control of the balloon. Methods of controlling the course of the balloon with account for increased safety measures were to be established to enable observations to be made over longer periods of time.

(3) Development of balloon-borne instruments. Devices for the systematic orientation of observation instruments were to be developed and brought into use within two to three years. A precise altimeter, devices for balloon control and other observation equipment were also to be developed.

(4) Establishment of test sites. Balloon flights were to be studied from temporary test sites, but within two or three years a permanent site was to be established and radio transmitting and receiving systems were to be developed.

Balloon tests were in fact carried out along these lines and the first launching took place on 29 July 1966 from the temporary site at Taiyo Village, Ibaraki Prefecture.

3. BALLOON TEST SITES

A site from which a balloon can be launched and tested is of course essential. A suitable temporary site was sought in April 1966 when the first-year plan for balloon development was being discussed.

Due to the meteorological conditions over Japan, a balloon, after being launched, would be carried eastward on the westerly wind. This, together with the fact that the rupture of a balloon usually occurs during its ascent, made it desirable to select a site on or near the east coast. In this way, any operational failure would result in the balloon falling into the sea rather than a populated area. This is a safety factor which the planners had considered in selecting a site.

Thus, a detailed survey was made in the Pacific coast area of the Kanto region and finally, as a result of the work done on 16 and 17 June, a site located at 1338 Oshige, Taiyo Village, Kashima District, Ibaraki Prefecture (140°34'00"E, 36°05'40"N) was selected and leased from the Taiyo Village Council (Figure 1). The site had an area of 2, 286 m^2.

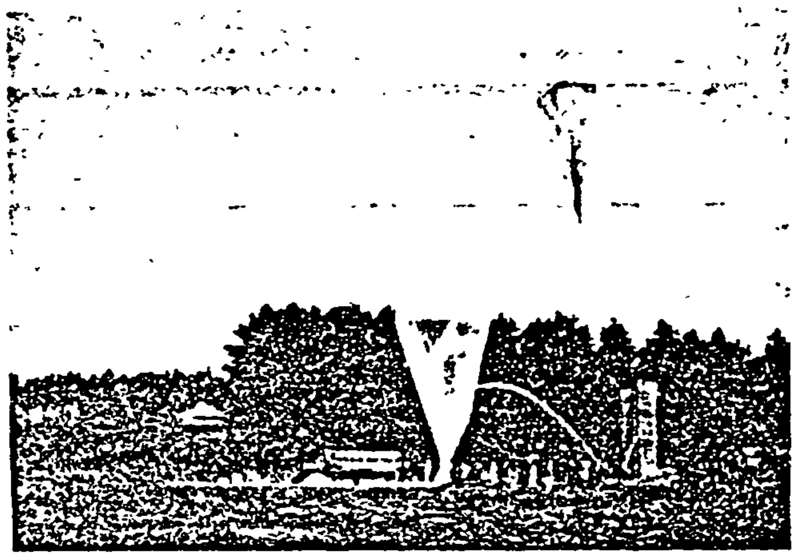

Figure 1. Taiyo Village Balloon Test Site

In the following year an auxiliary site at Asahimura in the neighborhood of Taiyo Village was also set up for use whenever the state of the surface wind was satisfactory. Thus, in 1966 and 1967 some 45 balloons were launched from these sites.

During these two years the capacity of the balloons had increased and the industrial belt in the Kashima District had continued to grow. As a result of these developments the test sites at Taiyo Village and Asahimura were no longer suitable from the safety point of view and, as a result of investigating other proposed sites, the testing was transferred to another temporary site at Haranomachi in the Fukushima Prefecture (140°55'55"E, 37°36'40"N). This site had an area of 12,000 m^2.

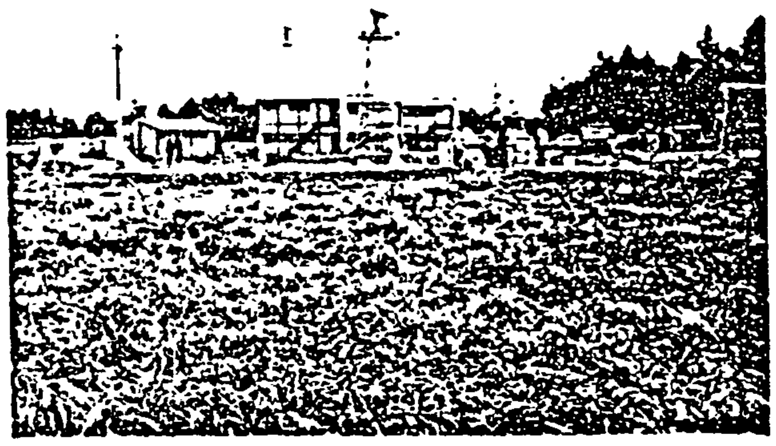

Figure 2. Haranomachi Balloon Test Site

Tests were carried out from the Haranomachi site for three years from 1968 to 1970, and some 93 balloons were launched. The search for a permanent test site was continued. The conditions that were considered essential were (1) location on the Pacific coast, (2) favorable meteorological conditions at ground level, (3) accountability of safety factors and (4) avoidance of flight corridors. With these points in mind a number of possible sites were investigated.

The investigation was conducted by Professor Maruyasu of the Institute of Industrial Science, the University of Tokyo, and his staff. As is shown in Table 1, the results of the work clearly indicated that the region around Sanriku was the most promising.

The budget for the Sanriku Balloon Center which is located in the Kese District, Iwate Prefecture (141°49'30"E, 39°09'30"N) was finalized in 1970 when balloon launching at the Haranomachi site was becoming difficult due to the presence of the Anchorage corridor to its east, and indeed the timing was very close from the point of view of the continuation of balloon testing and observation.

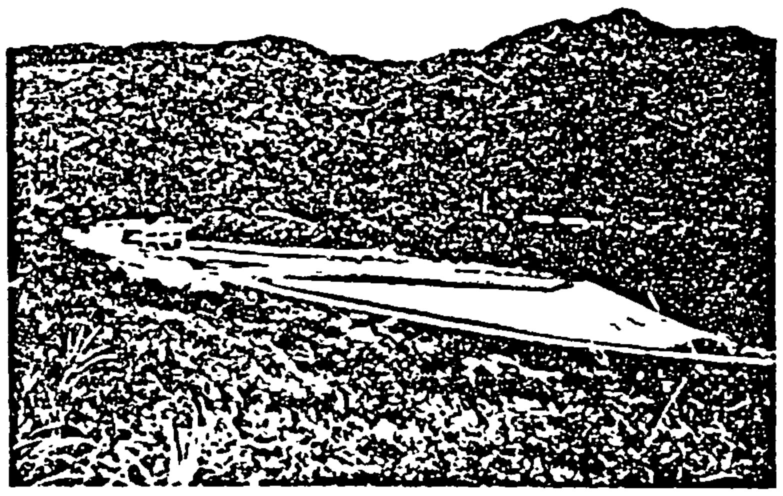

Figure 3. Sanriku Balloon Center

Only an outline of the Sanriku Balloon Center will be given here since the details have already been reported by Murai (1973) and Nishimura and Hirosawa (1973).

The permanent balloon center differs from the temporary test sites at Taiyo Village and Haranomachi in that it has a radio receiving station on top of a small hill situated about one kilometer away from the launch site. This was because of the topography of the land around Sanriku, and it was thought that the extended range of radio communication that was possible from this elevated site would outweigh all the disadvantages of having the station somewhat remote from the launch site. As a result of this siting, it was possible to communicate with a balloon at an altitude of 30 km and

Table 1. A Comparison of Proposed Balloon Sites

Location	Topography	Meteorological Conditions	Safety Factors	Air Corridors	Overall	
					Launching	Safety
Sanriku	Intermontane basin	Very favorable	Very safe	Safe	○	○
Haranomachi	Flat land	"	Near populated areas	Anchorage air corridor to the east	○	×
Taiyo Village	"	Strong winds	Near Kashima industrial zone	No general problems	×	△
Shimokita	"	"	Very safe	Safe	×	△
Boroku	Intermontane basin	"	Near Sendai	Rather close to Anchorage air corridor	×	△
Ishinomaki	Reclaimed land	"	Near populated areas	"	×	×
Iwanuma	River valley	Wind rather strong	"	Anchorage air corridor	△	×
Namie	Intermontane basin	Favorable	Close to nuclear power plant	"	○	×
Nasu	Plateau	Wind rather strong	Unsatisfactory because of air corridors; otherwise safe, but possibly cities may come under balloon flight path	Air corridors	△	×
Uchinoura	Intermontane basin	"	"	"	×	△
Shiomisaki	Flat land	Strong winds	Close to Sakakami industrial zone	"	×	△

a distance of 600 km to the east and 200 km to the west of the launch site while in the course of making observation.

The launch site was made up of a paved launch path, 120 m long and 20 m wide. This path was rather small compared to most foreign ones but as a result of improvements in launching techniques, it was possible to launch a balloon with a capacity of 200,000 m^3 in 1973.

4. DEVELOPMENT OF BALLOONS AND THEIR STANDARDIZATION

The first problem to be tackled after the inception of the Balloon Division at the Institute of Space and Aeronautical Science was the creation of balloons lighter in weight and capable of carrying a heavy payload in a stable level flight at a very high altitude.

Even before the Balloon Division was established, some work had been done into the fundamental design and manufacture of balloons (Fujimoto et al, 1962; Kawamura, 1966; Nishimura, 1966; Niu, 1966), and it was decided that these principles should still apply and that the work should start at the 5,000 m^3 level with a gradual increase to larger capacities.

Research into polyethylene films which had good low-temperature properties was pursued on a long-term basis and both Japanese and foreign data were investigated by the Balloon Discussion Group* which was made up of representatives from the Materials Division of the Institute of Space and Aeronautical Science and the Hirao Laboratory of the Institute of Industrial Science.

During the first year of the work it was found that it was not only the

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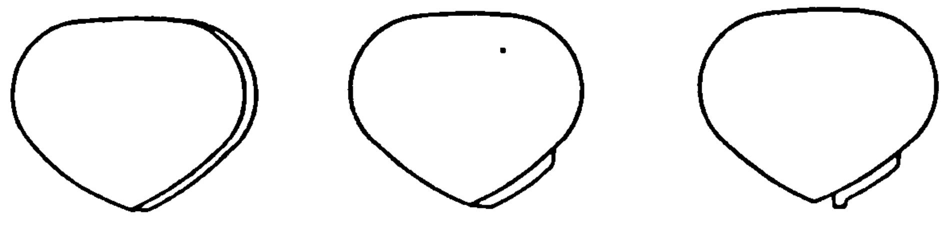
*This group had no fixed membership, but those present included Kawamura, Kanbe, Kuratani, Kawada, Nishimura, Ohara, Mitsuda and Fujii of the Institute of Space and Aeronautical Science, and Hirao and Okamoto of the Institute of Industrial Science. Representatives from Mitsubishi Petrochemicals, Unica Japan, and Dainippon Resins were also present.

polyethylene itself that affected the low-temperature properties of the film but that the conditions under which the film was processed were also very important, and it soon became clear that it was essential for the film to be produced under the condition that there was a balance in the biaxial elongation.

On the basis of this principle a large number of trial films were produced and their properties were thoroughly investigated. In 1970 film dies that were particularly suitable for the production were introduced, and the quality of the films was improved tremendously. The films that were made in this way were indeed in no way inferior to the "Strato-Film, the best balloon film at that time made in the United States. Details of these developments were reported by Kawada (1975) and Okamoto (1976).

The basic shape of a balloon was the natural shape (Fujimoto et al, 1962; Nishimura, 1966; Niu, 1966), and an escape tube was fitted to the balloon to prevent air from being sucked into it via the gas exhausting vent. The escape tube in the earlier balloons was attached from the very top, as shown in Figure 4, but as a result of the additional fitting to the balloon body, there was a concentration of stresses in the regions of the attachment during the balloon expansion and it became clear that this stress concentration did in fact cause the balloon to rupture. Thus, after 1968 the escape tube was fitted only to the lower part of the balloon as shown in the figure.



1966~1967

1968~1969

1970~

Figure 4. Attachment of the Escape Tube to the Balloon

Design modifications of the width of the area to which the escape tube was attached were carried out in 1968, but these caused the balloons to descend slightly when they were supposed to be maintaining a state of level flight in the upper atmosphere. It was thought that this was because some of the hydrogen gas in the escape tube was being driven out by the effects of the winds while the balloon was in level flight and so the shape of the tube was further modified in 1970 as shown in Figure 4. It was decided at the same time to limit the size of the dummy space caused by the escape tube to a minimum.

Then in 1973 when boomerang tests were carried out, air was found sucked into the balloon from the escape tube at an altitude of about 15 km so that the balloon remained suspended at this level for a period of two to three hours (Nishimura et al, 1973a). To prevent this, magnetic rubber was attached to the lower end of the tube which functioned effectively in preventing the ingress of air at too low an altitude so that the balloon could still ascend all the way up to its predetermined maximum altitude.

In the early stages of development, the rupture of a balloon during its ascent was found to have been caused by factors such as the quality of the film, the design of the balloon (especially of the escape tube) and unsuitable launching procedures. At the present time, however, the phenomenon of rupture of a balloon during ascent has been considerably reduced as a result of the improvements made in these areas and in a whole year at most one balloon can be expected to be lost through rupture. The state of the development of larger balloons which was the original objective of the institute is shown in Figure 5 where it is clear that the capacity rose from 50,000 m^3 in 1968 to 200,000 m^3 in 1973, the latter being the largest ever been launched outside the United States at that time. At present, a

500,000-m^3 balloon is being planned.

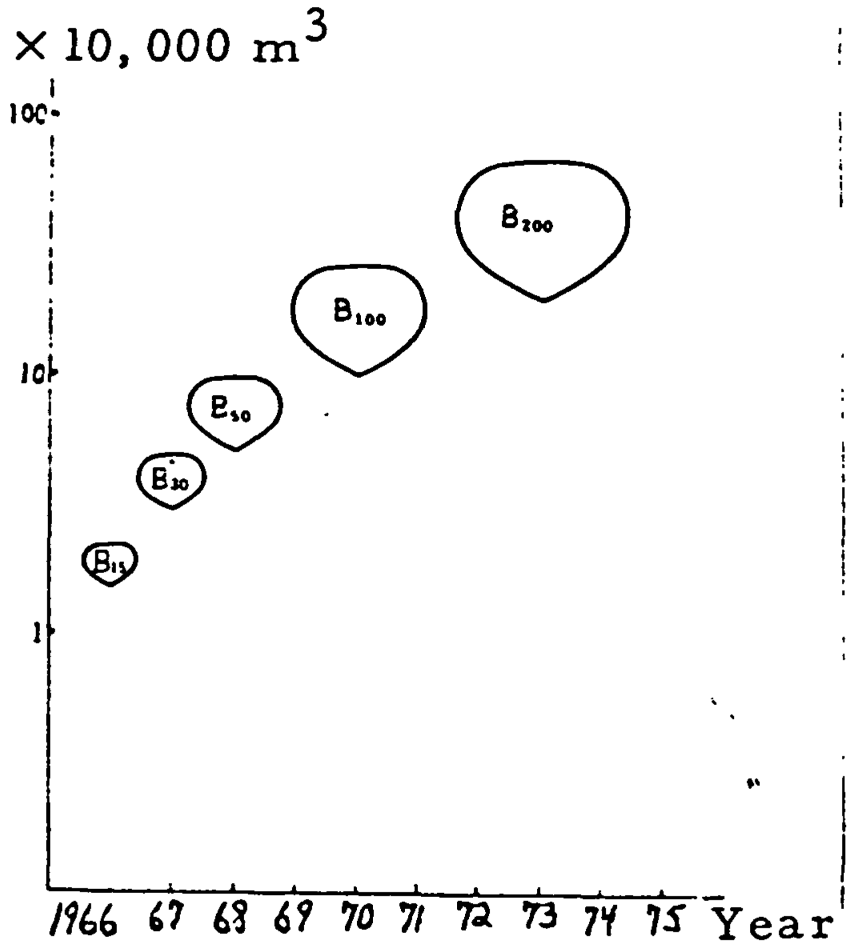


Figure 5. State of Development of Large Balloons

The increases in weight of the payloads during the years are shown in Figure 6 in which the improvements made in the methods of launching played an important role.

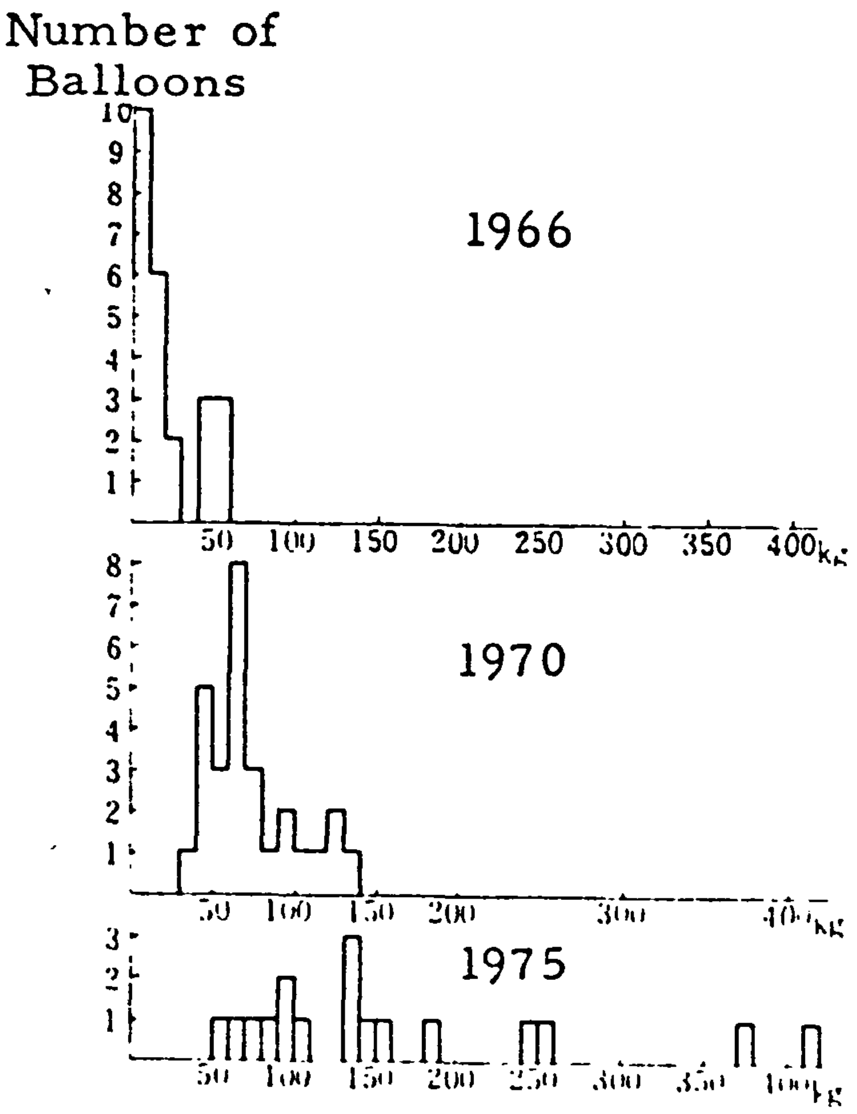


Figure 6. Changes in Weight of the Payloads

5. DIRECTION CONTROL

In observations using a balloon it is often necessary to fix the measuring instrument in a prescribed direction or to make it point~~ing~~ at a particular celestial body. Indeed, even before the concept of balloon sounding was raised at the Institute of Space and Aeronautical Science, a small east-west direction control device had been used in the observation of cosmic radiation in order to make use of the zonal effect of the radiation (Kawamura, 1966). The year before the inauguration of the Balloon Committee, the importance of direction control had been stressed by Professor Kawamura who was to become the chairman. Professor Kawamura had made prototype devices in the laboratories of the Department of Physics.

However, all of these early pieces of equipment were for use with simple observation instruments and since most of them were very complicated mechanically, it was felt desirable to produce equipment of a different type. Then, in 1968 when the idea of balloon observation started to gain momentum the demand for this type of equipment became great.

In fact two different control methods were considered.

In the first method the observation instrument which moved within the gondola was made to face in the intended direction. In order to stop the gondola reacting against the movement of the instrument, it was necessary to ensure that the moment of inertia of the gondola was high and this in turn necessitated increasing the size of the gondola. It was also necessary to connect all cables to the instrument by means of slip rings and the structure of such devices became rather complicated.

Although this method did suffer from the disadvantages noted above, the basic principle was simple and as a result it was widely adopted in countries such as the United States and France.

The other method involved orienting the gondola into the intended direction. Since, if such a method could be perfected, it would be possible to use several observation instruments simultaneously, it was decided that the method be developed.

In the design of such a mechanism, it was necessary to investigate the state of the external disturbances to which the gondola would be subjected. These external disturbances caused the gondola to rotate and oscillate.

The observation of these phenomena had been made right from the establishment of the Balloon Division. In the case of rotation, results could readily be obtained using a magnetic sensor on board the gondola. When the external disturbances were severe rotations occurred at the rate of about one revolution every ten minutes, whereas under normal conditions the situation was more relaxed and one revolution was completed every thirty minutes (Nishimura et al, 1971).

For oscillation, it was found that the system was surprisingly complicated by observing the movement of a pendulum that had been suspended from the balloon. When measuring instruments were loaded into the gondola however, they were accelerated by the oscillating movement of the gondola and this made it very difficult to measure the oscillation of the whole system.

It was finally decided to determine the oscillation by measuring the angular velocity using a light gyro, and an oscillation gauge based on this principle was produced. The oscillation gauge was first introduced in 1966 and as a result of early measurements, it was found that when in a state of level flight the oscillation angle of the gondola was less than one hundredth of a degree.

External disturbances were found moderate when the rate of rotation was slow and the angle of oscillation small.

Hence, it was concluded that a comparatively gentle method could be employed in the controlling mechanism, and such mechanisms are indeed still used during observations at the present time. Finally, let us consider the way in which the "untwining technique" was thought out.

The mechanism that was worked on initially was a gas jet. A torque was applied to the gondola by exhausting gas (carbon dioxide) through a jet, and it was possible to match the angular velocity of the gondola to the angle of divergence from the intended direction by controlling the amount of gas passing through the jet. Experiments with this system were carried out during 1967 and the results had a directional accuracy within two to three degrees (Fujii et al, 1969). However, the method required that gas cylinders be loaded onto the balloon and because of this and the fact that the amount of gas carried was finite, the effective period of control was limited. Thus, attention was diverted to direction control using the untwining technique (Nishimura et al, 1970).

The considerations in this case assumed the fact that the external disturbances were moderate. The rotation of the gondola is directly related to the rotation of the balloon which is caused by the external disturbance and which is transmitted to the gondola via the suspension cord. Hence, this motion can be cancelled out simply by twisting the cord by an amount equal to the extent of the rotation. However, it is also necessary to account for the stability of the control system in making the gondola face in the intended direction, and to bear in mind that observation will have to be made while the gondola is being rotated by the external disturbance. From the results of analyses, it is now known that the angular displacement from the intended direction, the angular velocity, and the angular acceleration may all be combined together quite well if the rate of the twist angle is fixed satisfactorily.

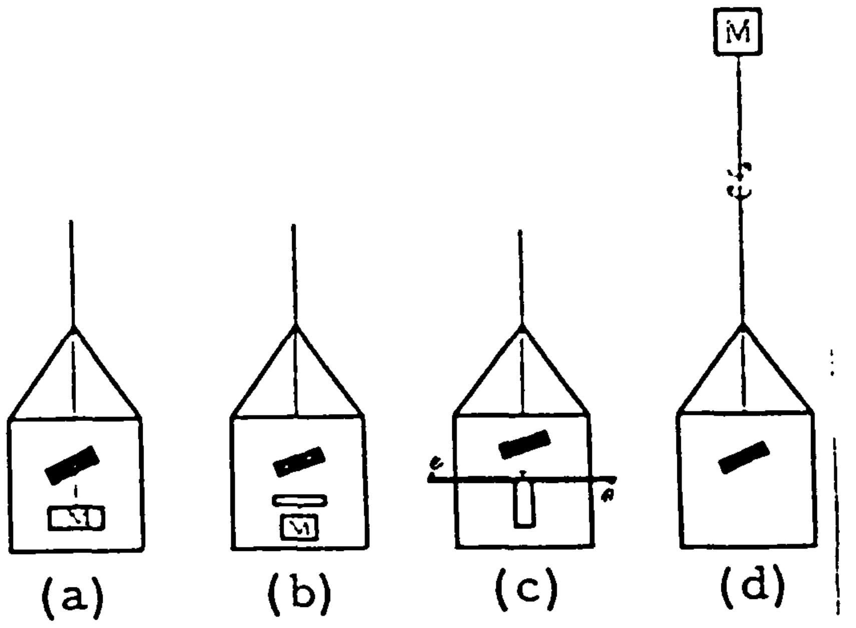


Figure 7. Directional Control Methods: (a) Direct-drive, (b) fly-wheel, (c) gas-jet, and (d) untwining

Tests were carried out in 1968 and refinements were added to the system every year to improve the directional accuracy. The effects of these improvements are shown in Figure 8.

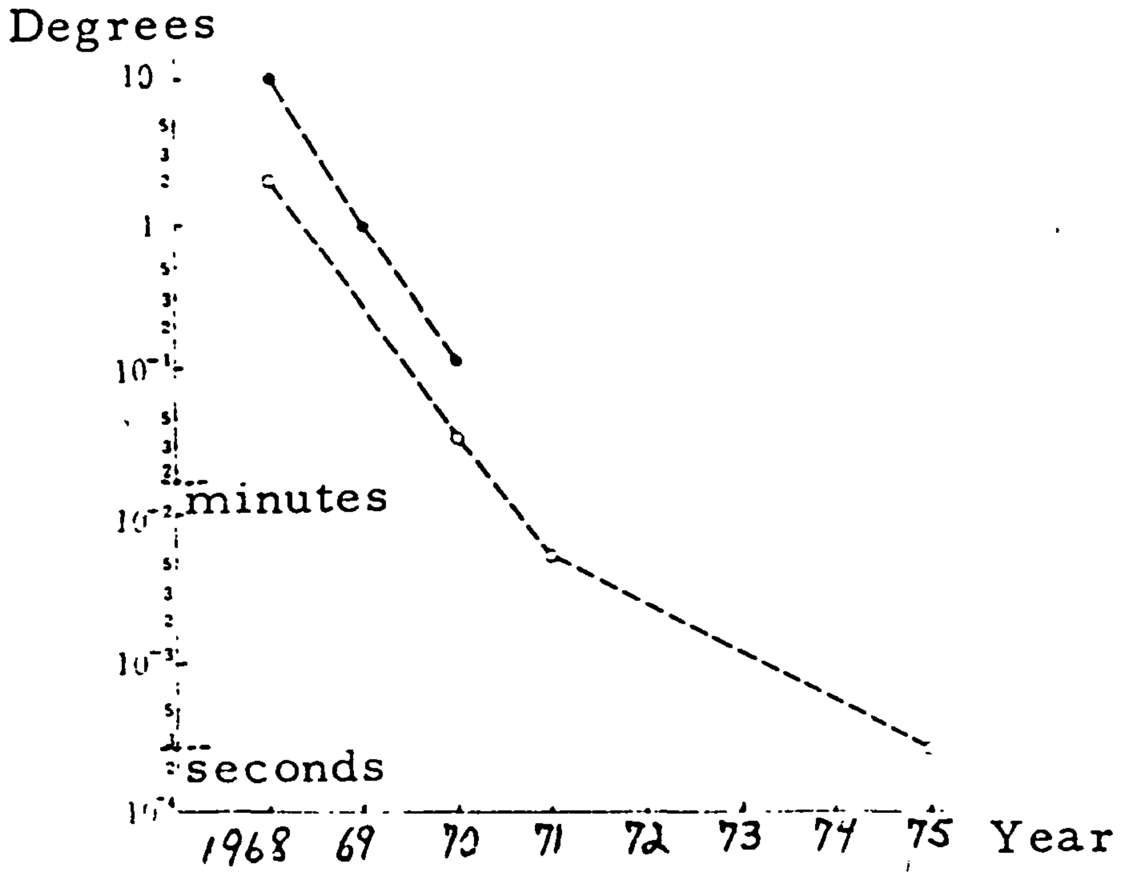


Figure 8. Changes in the Accuracy of Directional Control Systems. ● Untwining technique; o two-stage system

The untwining technique is not the only system with a directional accuracy within one degree however, and there are others whereby highly accurate control is achieved with a device fitted into the gondola. Controllers with two or more stages based on this idea have appeared on the scene since 1970. The improved state of directional accuracy that can now be achieved is of the order of seconds of a degree.

With the perfection of the untwining technique, it has become possible to plan observations which require directional control relatively easily. Observations of Cygnus X-ray stars, solar X-rays and infrared stars have been carried out using control devices of many types and out of the 228 balloons that were launched during the past decade, 45 involved directional control.

6. BALLOON-BORNE INSTRUMENTS

6.1 Telemetering and Command Systems

During the period when observations were made with nuclear emulsions, the principle function of telemetry was to give an indication of the altitude and location of the balloon and so it was only necessary to use a system that had been employed by the Japan Meteorological Agency for their radiosondes to monitor the winds, or one of the improved telemeters derived from these basic instruments. However, in rockoon experiments and in other balloon observations where part of the data had to be relayed by telemetry, FM-FM telemeters were used.

The development of telemetering systems began following the inception of the Balloon Division.

Initially, FM-FM telemetry in the 298 MHz band (Yasuda et al, 1967) and a single-channel proportional time system for sondes at 1680 MHz were used, but after 1968 consideration was given to simplification of the system which was then unified to FM-FM at 1680 MHz which is still in use at the present time. The system can have a maximum of seven channels and the subcarrier is of the IRIG standard. The maximum frequency was 22 KHz. Observations have also been carried out using the partial PCM method.

The command system used at first was of the 79.9-MHz singleton control four-channel type but in order to increase the number of command items and the stability against external noise, a doubleton six-channel type was introduced after 1968 and this has remained in use up to the present time.

Originally, the location of the balloon was verified by using a barometer and by measuring the altitude angle and the azimuth, but there was considerable uncertainty with this method and after 1968 range finding was done using a transponder. This system has also remained in use up to the present day.

The system was developed with the guidance of Professor Nomura of the Institute of Space and Aeronautical Science and consists of a ring made up by loading a command receiver and a transmitting telemeter on the balloon and sending out continuous waves of 5 KHz and 500 Hz from the ground, whereupon the distance up to the balloon can be estimated from the phase displacement in the signals (Nomura et al, 1969).

Almost no supplementary equipment needs to be loaded and although the system is simple, it is very effective for ascertaining the location and altitude and it plays a fail-safe role as far as safety and recovery of the balloon are concerned.

It has been reported that the system has also been used in the United States, but this should not be taken to mean that the distance of a balloon is measured in the same way as in Japan and other countries. The accuracy of distance measurement using this system is 200 - 300 m, and at the present time the results are fed on line into a mini computer and the altitude, location and rate of ascent are printed out from moment to moment by means of an XY plotter and a typewriter.

6.2 Altimeters

The aneroid barometers which are presently used with radiosondes by the Japan Meteorological Agency are made to operate with a good degree of accuracy at altitudes around 15 km (100 mb). They are not accurate when used at 30 km (10 mb) where sounding balloons are generally located. Consequently, two-stage aneroid barometers were designed and manufactured following the establishment of the Balloon Division. The first stage operates as a normal aneroid barometer, but several shapes and materials were tested for the second stage, and a mechanism that operates only from about 100 mb is used. The accuracy is about 1 mb at an altitude of 10 mb. This type of barometer is still being used at the present time.

Hypsometers were also investigated and some that were accurate to within 1 percent of the pressure were perfected around 1970 (Hirosawa, 1969; Hirosawa et al, 1971, 1973). The realization of these instruments has made it possible to investigate the vertical movement of a balloon to an accuracy of about ten meters. However, since the instrument depends on the liquid boiling point, it is rather complex to handle and is unsuitable for use when observations are to be made over an extended period of time, though it is constantly being improved at the present time.

6.3 Balloon Internal Pressure Gauges and Balloon Film Strain Gauges

Differential pressure gauges (Nishimura et al, 1968) and strain gauges (Kawada et al, 1969) were made to investigate the movement of balloons in the upper air and the stresses and strains to which the balloon film was being subjected. Tests were made between 1966 and 1969 using balloons that had been made from a variety of materials. The basic principle of the internal pressure gauge involved the application of a strain gauge and two types were tested, one being produced by the Balloon Division and the other being a remodelled product of the Toyo Instrument Co., Ltd. The sensitivity of the former type gauge was 0.05 gr/cm^2, whereas that of the latter was better by one order of magnitude.

The film strain gauges were developed in the Kawada Laboratory of the Materials Department of the Institute of Space and Aeronautical Science. They are capable of detecting about 100 percent ~~of the~~ strain.

Both of these instruments were balloon-borne and the pressures inside the balloon and the strains in the balloon film were measured at the time of launch and at balloon rupture. Between ten and twenty measurements were taken and the results provided useful fundamental data concerning the properties of the film and the changes that occurred in the upper atmosphere, and this has proved to be useful in the development of large balloons.

6.4 Oscillation Gauges (Nishimura et al, 1968)

As was discussed in Section 5, oscillation gauges are based on the principle of a light gyro and are a device for measuring the angle of oscillation of a gondola. The mechanism is made up of a pendulum to which a micromotor is attached and the fly wheel is made to rotate at 300 rpm. When oscillations are present the pendulum swings as a result of the gyro force. The sensitivity of the prototype gauges was to an angle of one second for a suspension cord of ten meters long.

Initial flight tests were made in 1967 and a number of observations using these gauges were carried out during the period up to 1970. As a result, it is now possible to clarify the movement of the gondola in the upper air. When two gauges are used in such a way that the directions of oscillation are at right angles to each other, the oscillation plane and the existence or otherwise of conical motions can also be detected.

6.5 Control Devices (Nishimura et al, 1973b)

A number of prototype gas exhaust valves and ballast valves that were suitable for controlling the ascent rate and the altitude of a balloon were produced between 1966 and 1972 and they were all given practical trials.

6.5.1 Ballast Valves

The ballast used consisted of steel balls with a diameter of 0.3 mm. They were prevented from falling out by a permanent magnet fixed to the dropping port. The dropping of ballast required a reduction of the magnetic force by passing an electric current in the appropriate direction. The dropping capacity was initially about one kilogram per minute, but valves that would allow ballast release at the rate of six kilograms per minute were developed later and they are still in use at the present time.

6.5.2 Gas Exhaust Valves

These were developed to stop the balloon during ascent or to make it descend from level flight. They were fitted on top of the balloon.

In the earlier models the valve was opened by means of an electromagnet for safety reasons and the gas used was hydrogen (Fujimoto et al, 1962; Nishimura, 1966; Nishimura et al, 1968; Niu, 1966). As a result, the stroke of the valve was short and the valves had a rather inadequate exhausting efficiency. Exhaust valves that were operated by compressed gas were developed later (Nishimura et al, 1968).

Since 1972, helium has been used in place of hydrogen and as a result of this changeover, more efficient motor-driven valves have been perfected. These valves are now used with boomerang balloons.

The reliability of these valves at low temperatures (-70°C) can be a problem because of the condensation on the outer surface of the balloon, and this has been particularly important in the development of safer and lighter balloons.

6.6 Ascent Gauges

The rate of ascent of a balloon is generally calculated from the results of observation of the altitude of the balloon. However, because of possible errors involved in the altitude measurement, errors are usually introduced when the rate of ascent or descent is calculated from data collected over a period of one minute. When the ascending or descending rate is slow, then particularly long periods of time must be allowed to make the necessary measurements.

Balloon-borne ascent gauges produced in 1962 worked on the same basic principle as those used in aircraft in which the difference between the pressure inside a box which has a leak and the external pressure is taken to be proportional to the rate of ascent or descent.

As was mentioned in Section 6.3, the sensitivity of the internal pressure gauges was high and as better differential pressure gauges were made, improved ascent gauges were also produced in 1966 and 1970. The sensitivity of these gauges in ascent or descent is about 20 cm/sec and the response time is 15 sec at an altitude of 15 km, and as has been mentioned earlier, these gauges are very effective in the control of boomerang balloons.

7. CONTROL OF BALLOONS (FOR EXTENDED FLIGHT)

One of the characteristic features of a balloon is that observation can be made over a longer period of time and the payload can still be recovered after the work has been completed.

The recovery of the payload after an extended flight is essential of course particularly when the observation involves the use of nuclear emulsions.

Consider briefly now the condition of the winds over Japan. The wind direction varies according to the time of year. In summer a westerly wind prevails below an altitude of 20 km, whereas above this level an easterly wind predominates. The easterly wind becomes weak in late autumn and reverses its course to become a westerly wind. Sometimes, it is temporarily replaced by a westerly wind as a result of changes in the atmospheric pressure distribution and so it cannot be stated categorically that there is an easterly wind prevailing continuously at that altitude throughout the summer period.

Thus, a balloon that is released from the ground is carried in an easterly direction on the westerly wind, but if it continues rising to an altitude above 20 km, then it will encounter the easterly wind and return in the direction of the launch site. Hence, a few hours after being launched the balloon will pass over the neighborhood of the launch site moving in a westerly direction.

Due to the long and narrow feature of the Japanese archipelago, the period of a balloon flight is limited to less than ten hours if recovery of the payload is anticipated.

The winds aloft were utilized very skillfully in 1960 by the Cosmic Radiation Laboratory of the Institute for Nuclear Study to investigate the possibility of extending the period of flight using the cycling technique (Fujimoto et al, 1962; Nishimura, 1966; Niu, 1966).

The cycling technique is used for flight control so that as the balloon passes over the launch site travelling in a westerly direction, it is made to descend into the zone of the westerlies and travel back towards the east after which it is made to ascend again into the zone of the easterlies. The idea was that by repeating this operation a number of times, the balloon could be held in the upper atmosphere for an extended period of time while remaining somewhere near the launch site.

The results of flight tests with this method were quite satisfactory and a flight of thirty hours was achieved in 1963.

The idea of controlling a balloon in this way was also taken up by the Balloon Division of the Institute of Space and Aeronautical Science following its inception when it was working on the development of large-capacity balloons and the improvement of the safety factors. It was not until 1972 that the Division has given its undivided attention to the establishment of control techniques.

7.1 Boomerang Balloons (Nishimura et al, 1974)

The substitution of helium for hydrogen as the balloon gas in 1972 made it possible to use exhaust valves that had a greater efficiency than those used previously.

The boomerang technique can be considered as a variation of the cycling technique. The ascent of the balloon is stopped temporarily at 15 km or so where the westerly wind is strong. The balloon is then carried along in an easterly direction by the westerly wind and then made to recommence its ascent while still within the range of radio communication, a few hundred kilometers away from the launch site. The balloon ascends to its final altitude and then slowly returns in the direction of the launch site at this altitude. A normal flight usually covers a distance of 100 to 200 km, but with the boomerang technique the distance is extended several hundred kilometers and as a result, the payload can still be recovered after being in flight for a period several times longer than normal (Figure 9).

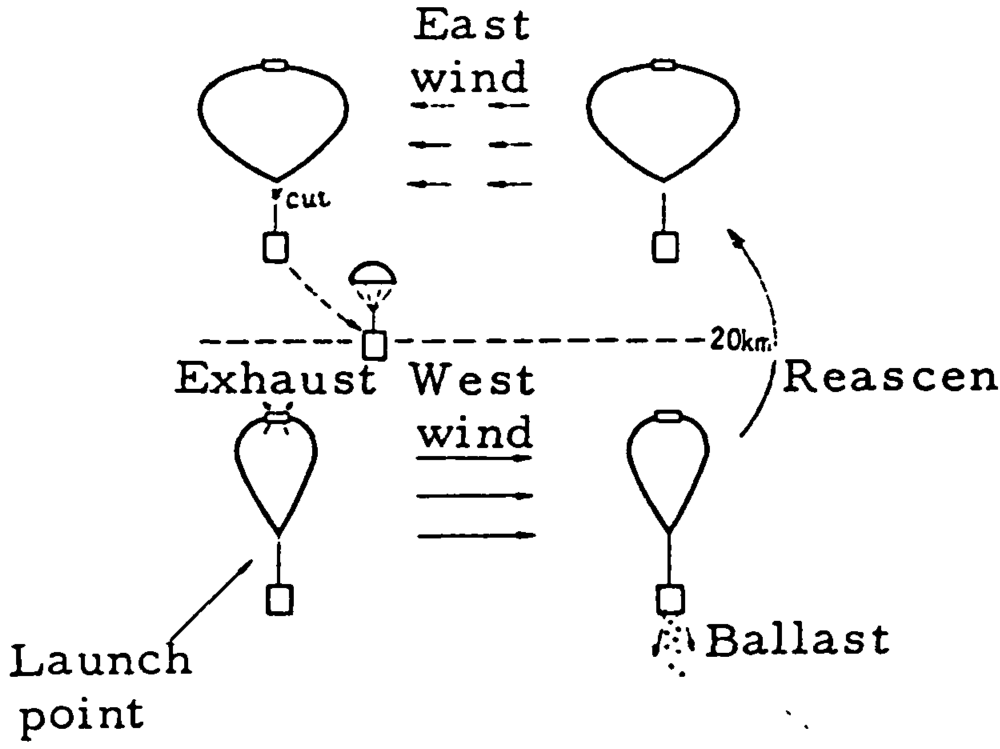


Figure 9. Boomerang Technique

Flight testing was carried out in 1972 and actual observation in 1973. By 1975 the technique had been used on six occasions and the period of flight extended to 30 hours.

There were early difficulties with the increased weight and volume of the electrical batteries required to run the telemeter and the observation instruments over the extended flight periods, but the problem was later overcome by the use of high-efficiency lithium batteries produced by the Matsushita Electric Industrial Co., Ltd. in 1973 (Ohta and Otsuka, 1974; 1975).

7.2 Programmed Boomerang Balloons (Nishimura et al, 1975<u>a</u>; 1975<u>b</u>)

The limiting distance for boomerang balloons is governed by the maximum distances at which the command signal to start and stop the jettisoning of ballast in order to make the balloon recommence its ascent can be ~~sent~~ received ~~out~~. This in fact means that the balloon must be within the range of radio communication for the initiation of the reascent which in real terms means that the limit is about 500 km to the east. In order to increase the time available for making observations even further, it was desirable to extend this span even further to the east. It was with this in mind that flight tests using programmed boomerang balloons were carried out in 1975. With the programmed boomerang technique the timing of the jettisoning of the ballast is set by a command signal which is sent after observing the wind conditions as the balloon travels eastward at an altitude of 15 km. In this way it is theoretically possible to extend the span of the balloon further to the east beyond the limits of radio communication (Figure 10).

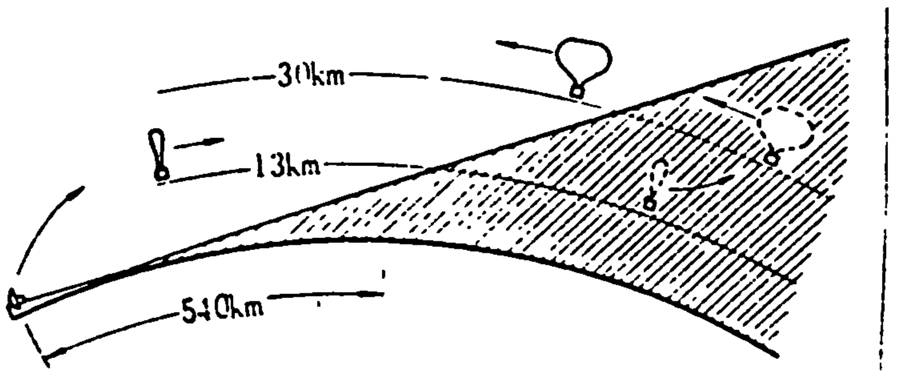


Figure 10. Programmed Boomerang Technique

In a test flight the recommencement of the ascent was started when the balloon reached 700 km to the east. At that time, however, the conditions of the easterly wind were poor and recovery was not possible, but it is thought that if the wind conditions were normal, recovery would be possible after a flight of more than 50 hours.

7.3 Patrol Balloons

In some types of observation, a long period of flight but not the recovery of the payload is necessary. Examples of such observations are X-ray and gamma-ray bursts which accompany eruptions on the surface of the sun and which are difficult to forecast and long-term variations in the intensity of X-ray stars. In such cases continuous patrolling over a period of several days is required.

The technique of using patrol balloons was developed in 1975 to observe gamma-ray bursts.

In the late autumn when the wind condition over Japan is changing, it seems that there is a region at an altitude between 30 and 40 km where there is almost no wind for a period of about a week. This fact was established from observations made in the past.

Two balloons released on 23 and 24 September were made to enter the region and as predicted, observations were successfully carried out over periods of 55 and 65 hours, respectively.

8. SCIENTIFIC BALLOONING ACTIVITIES IN JAPAN

The developments of balloon technology and observation in Japan are reported annually at the balloon symposium held under the sponsorship of the Institute of Space and Aeronautical Science. The first symposium which was held as a forum for discussion among the hundred or so interested workers from all over Japan took place in 1965, the same year the Balloon Committee was set up, and the eleventh symposium was held in 1975. When the first symposium was held the subject of balloons was in its infancy and the discussion was centered on the overall state of balloon observation in Japan and its prospects for the future rather than on the results that had been obtained using balloon techniques (Kawamura, 1966). The same sort of agenda were also discussed at the opening of the eleventh symposium.

Papers on balloon technology and observation are also published each year in the Bulletin of the Institute of Space and Aeronautical Science, Special Edition on Scientific Balloons, and in foreign technical journals. According to the latest lists the number of papers published has reached 185. The scope of the papers covers a very wide range of topics including astronomy, cosmic radiation, atmospheric physics, geophysics as well as the important subject of balloon technology.

On looking at the contents of the papers a tendency to change over the years becomes apparent. In the early stages there were virtually no large-scale projects since the balloons available were small and their load efficiency was poor. Furthermore, the observed results were nearly all connected with cosmic radiation since it was the workers in this field that had accumulated the most experience up to that time. These included the characteristics of primary electrons and the general properties of galactic X-rays. Then, the observation of atmospheric electricity and atmospheric ozone for which light-weight detectors were used was carried out and by further improving the observation devices, much important data was collected over a long period of time.

Since the untwining technique for balloon control was used in 1968, there have been some quite remarkable advances in the field of astronomical observations. There were also a number of observations made of the sun during the IASY.

Developments led on to the observation of solar infrared radiation and solar X-ray images and a number of important projects were set up for the IMS (International Magnetospheric Study). A further contribution to the observations of X-ray stars and new X-ray stars was also made possible with the advent of directional control equipment, and observations to ascertain the position of cygnus X-ray stars which had not been possible up to that time were successfully carried out. On the basis of these observations the radio source of cygnus X-ray stars was identified and became a subject of optical study.

From an analysis of the results of optical observations it appears that there are likely candidates for the black holes that are being considered at the present time, and it is thought that the black holes could be the origins of the celestial bodies.

The establishment of the Sanriku Balloon Center in 1971 has brought about stability in balloon operation and improvement in the capacity of the payload. Television cameras were balloon borne, solar telescopes were used, long-period fluctuations of cosmic radiation and ozone in the westerly belt were observed, and atmospheric composition was analyzed.

The advancement in technology has enabled tracking of infrared stars, observation of galactic infrared radiation and spectroscopic observation of solar ultraviolet radiation. The distribution of infrared radiations in the galactic system which was never observed in the past has now been clarified.

Balloon flights over an extended period of time were made possible by the advent of the boomerang technique, and this enabled observations of ultra heavy nuclei, high-energy heavy particles and primary electrons to be carried out, all of which were thought impossible before this time in Japan. New information concerning the acceleration and propagation of cosmic rays within the galaxy has also been acquired.

Remote sensing of the geomagnetic field has also been done by sending out a boomerang balloon a long way eastward over the sea, and it has been possible to gain a considerable amount of knowledge about the geomagnetic variations over the northeast region. The completion of the permanent base at Sanriku also made it possible to carry out tests in the winter. Observations were made of whistlers and other atmospherics when it was summer in the southern hemisphere but was January and February at Sanriku.

The appearance of patrol balloons in 1975 made it possible to extend the period of flight to 150 hours. Gamma-ray bursts, the cause of which still remains to be clarified, were observed using these balloons.

The detector used for gamma-ray bursts was an extension of the device for establishing the position of a cygnus X-ray source, and once the location of the burst is determined, it may prove possible to clarify the cause.

8.1 International Cooperation

Despite the achievements made in Japan over these years, observations at different geographical and geomagnetic latitudes could not have been possible without the cooperation of other countries.

The first joint venture was carried out by the Nagoya University and the Tata Institute of Fundamental Research of India. This was followed by the establishment of the International Cooperation Group at the Japan Society for the Promotion of Science which was later merged with the group at the Institute of Space and Aeronautical Science.

While the demands and expectations of international cooperation are high, they are only being met in part with research grants from individual foundations.

Work carried out at Hyderabad included the observation of galactic X-rays and gamma-rays and the simultaneous optical observation of Scorpio X-rays. Highly accurate results were obtained for the gamma-rays as important results for the generating mechanism of the Scorpio X-ray source. In 1974 the location of an X-ray source in a nebula was identified by utilizing the lunar eclipse of the Crab Nebula.

Under the sponsorship of the Japan Society for the Promotion of Science, observations of ozone have been made with the University of Utah and atmospheric ions with the University of Wyoming. Investigations of the spatial distribution of auroral X-ray sources which are of particular interest to the Institute of Space and Aeronautical Science have also been carried out with the University of Washington. Joint studies of primary electrons and X-ray images of the Crab Nebula are being pursued.

Talks are progressing on the subject of joint observation of the southern sky with Australia and Northern Europe, and it appears that this will be the next stage of cooperation.

It is now thought that on the basis of the observed results accumulated and the observation devices developed in Japan, certain joint efforts will continue and that there will be a need for further development in balloon matters in Japan in the future.

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4. Balloons Launched in Japan

Overall Serial Number	From Taiyo Village	From Haran-omachi	From Shiomi-saki	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
1	1			B_{01}-1	7/29/66	22:23	Flight test	16		1st testing fiscal 196
2	2			B_{01}-2	7/31/66	22:53	"	"		
3	3			B_1-1	8/3/66	16:01	"	20		
4	4			B_1-2	8/7/66	16:52	Cosmic dust	26		
5	5			T_5	8/9/66	4:03	X-rays	33	○	
6	6			B_5-1	8/9/66	12:37	Flight test	16	○	
7	7			B_{15}-2	8/9/66	19:15	X-rays	34	○	
8	8			B_{15}-1	8/10/66	13:35	Primary electrons	16	○	
9	9			B_{01}-3	8/9/66	23:16	Flight test	15	○	2nd testing fiscal 196
10	10			$B_{01}H$-1	8/10/66	22:50	"	18	○	
11	11			B_{01}-4	9/2/66	00:00	"	15		
12	12			B_1H-1	9/2/66	4:10	"	9	○	
13	13			B_{01}-5	9/3/66	18:25	Atmospheric electricity	18		
14	14			B_1-4	9/20/66	18:32	"	25		3rd testing fiscal 196
15	15			B_{15}-3	9/21/66	18:15	Flight test	35	○	
16	16			B_1-3	9/22/66	16:30	Atmospheric electricity	25		
17	17			B_2-1	9/27/66	2:38	Zodiacal light	25	○	
18	18			B_1-5	9/27/66	18:15	Atmospheric electricity	30	○	
19	19			B_1-6	9/28/66	17:47	Cosmic dust	25		
20	20			B_5-3	9/29/66	4:17	Heavy particles	30	○	
21	21			B_5-4	9/29/66	13:15	Solar gamma-rays	32		

Overall Serial Number	From Taiyo Village	From Haran-omachi	From Shiomi-saki	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
22	22			B_5-5	10/2/66	19:30	Humidity	—		
23	23			B_5H-1	10/2/66	1:17	Flight test	34		
24	24			B_{15}-4	10/7/66	5:30	Primary electrons	35	○	
25			1	B_{26}	9/27/66	17:55	Cosmic rays	23	○	4th testing f fiscal 1966
26			2	B_{26}	10/17/66	—		—		Balloon ruptured while jecting hydr
27	25			B_1-8	7/24/67	0:27	Oscillation gauge	25	○	1st testing f fiscal 1967
28	26			B_{01}-6	7/24/67	8:37	Strain, internal pressure, automatic camera	13		
29	27			B_{01}-7	7/28/67	7:15	Strain, internal pressure, camera	13	○	
30	28			B_1-7	8/19/67	23:58	Exhaust valve, internal temperature and pressure	20		2nd testing f fiscal 1967
31	29			B_1-9	8/21/67	0:57	Direction adjustment	20		
32	30			B_5-5	8/23/67	7:35	Ozone, oscillation gauge	3	○	
33	31			B_{15}-5	8/25/67	—	Exhaust valve	25	○	
34	32			B_5-6	9/8/67	4:52	X-rays	32	○	
35	33			B_{15}-6	9/19/67	7:55	Heavy particles	35	○	
36	34			B_1-12	9/22/67	9:56	Solar infrared	22	○	
37	35			B_{15}-9	9/23/67	21:30	Heavy particles	35		
38	36			B_1-13	9/24/67	18:20	Cosmic dust	25		
39	37			B_2-3	9/25/67	3:30	Atmospheric electric field	—		Some of th instrument recovered

Overall Serial Number	From Taiyo Village	From Harano-machi	From Shiomi-saki	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
40	38			B_{15}-8	9/27/67	6:43	Solar neutrons, γ-rays	18		
41	39			B_{15}-7	10/5/67	3:10	Primary electrons	34		
42	40			B_{20}-1	10/5/67	16:19	Galactic γ-rays	16		Asahimura
43	41			B_{20}-2	10/6/67	16:19	X-rays	16		"
44	42			B_{5}-8	10/19/67	10:56	Ozone	27		
45	43			B_{2}-2	10/21/67	3:08	Atmospheric ion density	24		
46	44			B_{5}-7	10/23/67	15:51	Launcher test	15		Asahimura
47	45			B_{30}-1	10/24/67	18:20	Flight test	15		"
48			3	B_{35}						3rd testing fiscal 1967 balloon ruptured
49		1		BC_{01}-1	7/20/68		Flight test	18		1st testing f fiscal 1968
50		2		BC_{01}-2	7/21/68	6:18	"	19		
51		3		BC_{01}-3	7/21/68	16:31	"	19		
52		4		BC_{01}-4	7/22/68	5:58	"	19		
53		5		B_{2}-4	7/25/68	15:08	Ozone	25	○	
54		6		BC_{01}-5	7/26/68	8:30	Flight test	17	○	
55		7		B_{1}-15	7/30/68	17:31	"	22	○	
56		8		BC_{01}-6	8/18/68	13:05	"	19		2nd testing fiscal 196
57		9		B_{01}-8	8/19/68	10:35	"	17		
58		10		B_{2}-9	8/19/68	13:45	Ozone	28	○	
59		11		B_{01}-9	8/21/68	12:23	Flight test	13.5		
60		12		BC_{1}-1	8/21/68	18:33	"	26		

Overall Serial Number	From Taiyo Village	From Haran-omachi	From Shiomi-saki	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
61		13		B_1-14	8/25/68	11:44	Flight test	23	○	
62		14		B_5-12	8/25/68	17:55	X-ray	32	○	
63		15		B_1-20	8/26/68	00:02	Zodiacal light	20		
64		16		B_1-16	8/26/68	12:59	Cosmic dust	23		
65		17		B_2-7	8/26/68	23:23	Airglows	23		
66		18		B_{30}-2	8/27/68	14:46	Flight test	31	○	
67		19		B_1-18	9/1/68	10:48	Electric field	23		
68		20		B_{15}-10	9/2/68	17:35	γ-rays	15		
69		21		B_2-6	9/5/68	8:59	Solar infrared	24	○	
70		22		B_2-5	9/6/68	9:15	Solar γ-rays	28	○	
71		23		B_2-8	9/6/68	18:20	Ionization	27	○	
72		24		B_1-19	9/9/68	12:48	Atmospheric electricity	22		
73		25		B_{20}-4	9/12/68	16:54	Heavy primaries, γ-rays	15		
74		26		B_{30}-3	9/16/68	12:48	Primary electrons	35	○	
75		27		B_{30}-4	9/19/68	15:22	X-rays	33		
76		28		B_{20}-5	9/23/68	15:16	"	32		
77		29		B_5-2	9/24/68	17:52	Cosmic dust	30	○	
78		30		B_5-9	9/27/68	7:56	Solar neutrons, γ-rays	27	○	
79		31		B_5-10	9/28/68	7:43	Solar neutrons	30	○	
80		32		B_{20}-3	9/28/68	17:33	Flight test	19		
81			4	B_{35}-1	10/12/68	21:09		28		3rd testing fiscal 196 Shiraham
82		33		B_{01}-12	7/18/69	15:22	Balloon material	17	○	1st testing fiscal 196

Overall Serial Number	From Taiyo Village	From Haran-omachi	From Shiomi-saki	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
83		34		B_1-24	7/22/69	14:38	Atmospheric ozone	22		
84		35		B_{01}-10	7/27/69	14:45	Flight test	16	○	
85		36		B_{01}-11	7/27/69	18:14	"	14	○	
86		37		B_2-10	7/28/69	9:32	Solar neutrons	3	○	
87		38		B_1-21	7/29/69	15:30	Flight test	22	○	
88		39		B_{50}-1	8/20/69	8:47	"	40		2nd testing fiscal 196
89		40		B_2-20	8/21/69	10:11	Direction adjustment device testing	25	○	
90		41		B_5-18	8/22/69	9:58	Instrument testing	26	○	
91		42		B_2-13	8/28/69	8:49	Solar γ-rays	26	○	
92		43		B_2-14	8/29/69	8:35	"	26	○	
93		44		B_1-22	9/3/69	10:11	Flight test	22	○	
94		45		B_1-25	9/5/69	18:15	Atmospheric ions	22	○	
95		46		B_2-18	9/8/69	17:40	Atmospheric electricity	25	○	
96		47		B_2-15	9/9/69	6:36	Cosmic dust	26	○	
97		48		B_2-17	9/10/69	8:23	Solar infrared	23	○	
98		49		B_2-19	9/11/69	19:27	Ionization	24	○	
99		50		B_{30}-7	9/13/69	5:05	Primary electrons	35	○	
100		51		B_2-16	9/14/69	18:30	Cosmic dust	26	○	
101		52		B_1-17	9/17/69	20:00	Nightglow infrared	23		
102		53		B_5-17	9/18/69	21:40	Zodiacal light and nightglow infrared	26	○	
103		54		B_{50}-2	9/20/69	18:40	Flight test	37		
104		55		B_{50}-3	9/23/69	10:19	Galactic X-rays	37		
105		56		B_2-11	9/26/69	7:21	Solar neutrons	26		

Overall Serial Number	From Taiyo Village	From Haran-omachi	From Shiomi-saki	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
106		57		B_{15}-11	9/27/69	9:35	Solar X-rays	32		
107		58		B_{1}-26	9/27/69	17:03	Magnetic field	21		
108		59		B_{5}-15	9/28/69	7:57	Solar neutrons and γ-rays	26		
109		60		B_{5}-14	9/29/69	2:59	"	29		
110		61		B_{30}-5	9/29/69	21:50	Primary heavy particles	35		
111		62		B_{1}-23	9/30/69	15:42	Flight test	21		
112		63		B_{1}-27	9/30/69	21:07	Atmospheric ions	20		
113		64		B_{2}-21	7/15/70	15:29	Direction adjustment	25	○	1st testing fiscal 197
114		65		B_{5}-20	7/20/70	9:55	Instrument testing	27	○	
115		66		B_{100}-1	7/21/70	18:03	Flight test	13	○	
116		67		B_{15}-5	7/26/70	8:09	Solar X-rays	34	○	
117		68		B_{2}-12	7/26/70	9:22	Solar neutrons	28	○	
118		69		B_{5}-19	9/29/70	16:13	Instrument testing	29	○	
119		70		B_{50}-5	8/31/70	14:48	Scorpio X-rays	37.2	○	2nd testing fiscal 197
120		71		B_{5}-16	9/2/70	7:26	Solar γ-rays	30	○	
121		72		B_{2}-27	9/4/70	17:52	Magnetic field	26		
122		73		B_{5}-25	9/5/70	7:33	Solar neutrons and γ-rays	29		
123		74		B_{5}-29	9/5/70	22:53	Nightglow infrared	28	○	
124		75		B_{30}-9	9/7/70	16:16	Cygnus X-rays	36	○	
125		76		B_{2}-26	9/9/70	16:16	Ionization	26	○	
126		77		B_{2}-22	9/8/70	17:48	Direction adjustment	24	○	

Overall Serial Number	From Taiyo Village	From Haran-omachi	From Shiomi-saki	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
127		78		B_5-13	9/11/70	18:39	Flight test	26	○	
128		79		B_5-22	9/13/70	17:14	Cosmic dust	32	○	
129		80		B_5-21	9/14/70	8:00	Solar infrared	27	○	
130		81		B_2-23	9/16/70	7:57	Cosmic dust	22.4	○	
131		82		B_{50}-6	9/17/70	8:52	Primary electrons	38		
132		83		B_{100}-2	9/19/70	16:57	Flight test	42.6	○	
133		84		B_{50}-4	9/20/70	9:27	"	32		
134		85		B_5-27	9/21/70	23:20	Atmospheric ions	30.5		
135		86		B_5-28	9/24/70	8:13	Atmospheric electric field and electricity	28		
136		87		B_{30}-10	9/24/70	19:54	Primary electrons	36	○	
137		88		B_2-25	9/25/70	16:24	ULF atmospherics	24		
138		89		B_{30}-6	9/27/70	14:50	Cygnus X-rays	36	○	
139		90		B_{30}-8	9/28/70	8:44	Primary heavy particles	35	○	
140		91		B_{15}-17	9/30/70	8:34	Galactic γ-rays	33.7		
141		92		B_5-24	10/2/70	1:13	Solar neutrons	35	○	
142		93		B_{15}-12	10/2/70	15:59	Instrument testing	30	○	

Overall Serial Number	From Sanriku	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
143	1	B_5-37	9/3/71	9:49	Cosmic dust	31	○	
144	2	B_5-31	9/7/71	8:56	Parachute testing	28	○	
145	3	B_5-33	9/14/71	9:01	Microstructure of solar disk	26	○	
146	4	B_5-32	9/15/71	8:34	Solar infrared	28	○	
147	5	B_{15}-13	9/16/71	9:11	Solar ultraviolet	34	○	
148	6	B_{15}-16	9/16/71	22:25	Heavy particles	31	○	
149	7	B_5-30	9/17/71	17:27	Direction adjustment	30	○	
150	8	B_{30}-11	9/18/71	16:57	Instrument testing	37	○	
151	9	B_{50}-7	9/28/71	15:47	Cygnus X-ray	39		
152	10	B_{15}-18	9/30/71	9:00	γ-rays	32		
153	11	B_{30}-13	10/6/71	9:28	α-particles, heavy particles	36	○	
154	12	B_5-36	10/7/71	16:43	Atmospheric electric field and electricity	28		
155	13	B_5-34	10/9/71	16:47	Galactic infrared	26		
156	14	B_2-24	1/31/72	17:26	Flight test	24		
157	15	B_{15}-19	2/3/72	19:56	Whistlers	32		
158	16	B_5-38	2/4/72	9:01	Rupture test	28		
159	17	B_{15}-20	2/6/72	8:35	Whistlers	33	○	
160	18	B_5-39	2/12/72	7:54	Flight test	29		
161	19	B_2-28	2/13/72	7:41	"	24		
162	20	B_2-30	6/22/72	8:30	Magnetic field measurement	26	○	
163	21	B_2-31	6/23/72	16:03	Water vapor	25	○	
164	22	B_5-41	6/25/72	8:00	ULF atmospherics	29	○	

Overall Serial Number	From Sanriku	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
165	23	B_5-40	6/25/72	16:05	Ion spectra	28	○	
166	24	B_5-35	6/29/72	8:35	Flight test	29		
167	25	B_5-26	7/7/72	8:23	Solar neutrons	29		
168	26	B_5-47	9/6/72	17:32	Flight test	25	○	
169	27	B_2-29	9/10/72	21:02	Nightglow infrared	22.5		
170	28	B_5-45	9/12/72	9:05	Microstructure of solar disk	22	○	
171	29	B_5-43	9/13/72	22:58	Zodiacal light	26		
172	30	B_2-32	9/18/72	17:21	Cosmic-ray short-period fluctuation	19.5	○	
173	31	B_5-44	9/20/72	8:43	Solar infrared	26.5		
174	32	B_{30}-14	9/21/72	8:43	Solar ultraviolet	34.5		
175	33	B_{30}-12	9/22/72	9:36	Galactic X-rays	36.5		
176	34	B_5-42	10/5/72	8:29	Atmospheric composition	25		
177	35	B_{15}-21	10/7/72	14:25	Galactic X-rays	35		
178	36	B_{15}-14	10/8/72	22:53	Zodiacal light and stellar field light	—		Balloon ruptured
179	37	B_5-46	10/10/72	15:38	Atmospheric electricity	26		
180	38	B_{50}-8	10/12/72	8:45	Primary electrons	35		
181	39	B_5-49	2/1/73	8:01	Ion spectra	—	○	Payload was cut off from balloon
182	40	B_5-48	2/4/73	8:37	Flight test	27		
183	41	B_{15}-22	5/27/73	17:37	"	30	○	Boomerang technique
184	42	B_{50}-10	6/2/73	19:26	Primary cosmic rays	33	○	"
185	43	B_{50}-11	6/5/73	19:04	Primary electrons	33	○	"

Overall Serial Number	From Sanriku	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
186	44	B_{15}-23	9/15/73	8:06	Microstructure of solar disk	28	○	
187	45	B_5-51	9/28/73	—	Cosmic-ray short-period fluctuation	—	○	Balloon ruptured on ground
188	46	B_1-28	9/29/73	17:20	Flight test	31		
189	47	B_5-52	10/1/73	20:42	Nightglow O_2, OH	27		
190	48	B_{15}-24	10/2/73	22:45	Zodiacal light	30		
191	49	B_{30}-16	10/3/73	8:00	Solar X-rays	37		
192	50	B_5-50	10/6/73	8:26	Instrument testing	27.5		
193	51	B_{30}-15	10/9/73	8:29	Hercules X-rays	35		
194	52	B_5-55	10/12/73	8:19	Ion spectra	26		
195	53	B_5-56	10/18/73	16:27	Electric field and gravity waves	27		
196	54	B_{200}-1	10/21/73	6:58	Flight test	43		
197	55	B_{50}-9	10/24/73	16:05	Rain γ-rays	23.5		Balloon ruptured
198	56	B01-13	1/26/74	11:26	Flight test	19		Nylon-12 film
199	57	B_5-54	1/27/74	9:54	Whistlers	26	○	
200	58	B_5-51	5/28/74	18:49	Cosmic-ray short-period fluctuation	18	○	
201	59	B_5-53	5/30/74	12:22	Photochemistry of stratosphere	28		
202	60	B_5-57	6/4/74	17:04	Magnetic field measurement	13		Boomerang technique, balloon ruptured
203	61	B_{30}-18	6/7/74	19:44	High-energy particles	31	○	Boomerang technique
204	62	B_{30}-17	6/13/74	19:39	Primary cosmic rays	27	○	Boomerang technique, balloon ruptured

Overall Serial Number	From Sanriku	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
205	63	B_{15}-25	6/15/74	14:58	Atmospheric composition	30	○	
206	64	B_5-58	6/23/74	20:46	Airglows, zodiacal light	25		
207	65	B_{50}-12	9/11/74	7:25	Solar ultraviolet	—	○	Launch failure
208	66	B_5-59	9/13/74	21:10	Infrared spectra of stars	25	○	
209	67	B_5-60	10/6/74	8:56	Level testing	28		
210	68	B_{15}-26	10/8/74	8:10	Instrument testing	32		
211	69	B_2-33	10/8/74	15:51	"	24		
212	70	B_5-62	5/23/75	17:42	Cosmic-ray short-period fluctuation	18		
213	71	B_{15}-28	5/25/75	7:40	Atmospheric composition	29	○	
214	72	B_5-61	5/29/75	7:12	Magnetic field measurement	28	○	Boomerang technique
215	73	B_{30}-19	5/30/75	18:04	Ultrahigh-energy particles	30	○	Boomerang technique, balloon ruptured
216	74	B_5-65	6/13/75	19:39	Airglows and zodiacal light	24	○	
217	75	B_5-64	6/16/75	18:29	Galactic infrared	25	○	
218	76	B_5-63	6/17/75	18:31	Infrared spectra of stars	24.5	○	
219	77	B_{15}-29	6/20/75	7:27	Instrument testing	33	○	Programmed boomerang technique
220	78	B_{15}-31	9/9/75	20:19	Infrared zodiacal light, galactic light	30		
221	79	B_{80}-1	9/11/75	7:38	Solar ultraviolet	38		

Overall Serial Number	From Sanriku	Balloon	Launch Date	Time (hrs)	Experimental Objectives	Altitude Attained (km)	Recovery	Remarks
222	80	B_{15}-30	9/16/75	7:46	Microstructure of solar disk	—		Balloon ruptured
223	81	B_{30}-22	9/23/75	8:33	Flight test	37		
224	82	B_{30}-20	9/24/75	17:07	γ-ray burst	36		
225	83	B_{30}-21	10/4/75	16:08	Cyg X-1, Her X-1	35		
226	84	B_5-67	10/6/75	16:34	Atmospheric electric field	27		
227	85	B_5-66	10/9/75	7:41	Ozone	28	○	
228	86	B_5-68	10/11/75	8:50	Ions, aerosols	24		

Note: The subscripts of B represent the volume of the balloon in units of 1,000 m^3; for example, $B_{01} = 100\ m^3$, $B_1 = 1,000\ m^3$ and $B_5 = 5,000\ m^3$. C shows a cylindrical-shape balloon and T a tethered balloon. H indicates that the balloon was made of a very thin film which was used in the early stage of development.