Recent Developments and Near-Term Expectations for the NASA Balloon Program

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The NASA Balloon Program has progressed from a total hiatus in the fall of 1985 to an unprecedented flight success rate in 1988–89. Using heavy-lift balloons being regularly supplied by two manufacturers, the program has provided a timely response for investigations of Supernova 1987A from Australia, low-energy cosmic ray investigations from Canada during periods of near-solar-minimum activity, and routine domestic turnaround flights for a variety of investigations. Efforts are underway to develop a reliable long-duration flight capability at both midlatitudes and Antarctica, following test flights from Australia to South America. Meanwhile, reevaluation of balloon flight safety has resulted in severe constraints on flights launched from the National Scientific Balloon Facility in Palestine, Texas. The future program must rely heavily on the use of remote launch sites to meet the growing requirements for more frequent and longer duration flights. This paper reviews the recent history and near-term future activities of the program.

Introduction

THE NASA Balloon Program conducts approximately 50 high-altitude balloon flights per year, predominantly in support of the astrophysics, space physics, and upper atmosphere research programs. The flights, which are used for both fundamental science investigations and for tests of hardware for future space missions, have generally been carried out from the National Scientific Balloon Facility (NSBF) at Palestine, Texas. Remote launch sites have traditionally been used to accomplish specific scientific objectives, e.g., those requiring the low geomagnetic cutoff at high geographic latitudes or celestial targets not observable from Palestine. Flights requiring more than several hours of observations are typically carried out during the so-called "turnaround" seasons, those few weeks during both the spring and fall when high-altitude winds are slow and variable because the prevailing east-west high-altitude wind direction is reversing.

The current balloon program relies on five standard balloons having the characteristics and capabilities given in Table 1. There are three basic balloon sizes, two of which have heavy (H) versions characterized by greater effective wall thickness, i.e., more caps. Only one of the balloons is designed for a nominal float altitude of 130,000 ft, although as shown in Fig. 1 a range of altitudes can be accommodated within the minimum and maximum weight limits. The science payload weights that can be accommodated depend primarily on the flight time desired and the time of day of the launch. Payloads up to a few hundred pounds can be flown on much smaller balloons (e.g., 0.25-3 MCF; 1 MCF = 10^6 ft^3) that are not included with the standard heavy-payload balloons listed in Table 1.

Balloon Program Hiatus and Recovery

The program was plagued with numerous catastrophic balloon failures between 1983 and 1985, especially for flights with liftoff weights exceeding about 5000 lb.[1] Before September 1983 the historical success rate for <5000 lb payloads was about 85%, although for >5000 lb payloads it had been only about 67%. After September 1983 the success rate for >5000 lb payloads dropped to about 30%, with only a few percent drop in the rate for <5000 lb payloads. During this trying period, in the interest of safety, payloads >3500 lb were not permitted to be launched from the NSBF.

The reason for the increased balloon failures has never been determined, although the failure investigations concluded that the most probable cause was some unidentified material change or changes. The failure rate was apparently correlated with the "stress index," which is a number representative of the stress along the balloon gores in an ascending balloon[2]; this index is calculated using a simple hoop equation for cylindrical stress. Figure 2 shows that the dependence was quite strong for balloons made after 1980 but rather weak for balloons made before 1980.

The 1985 fall turnaround season had failures approaching 100%. This led to the flight program being completely shut down in November 1985. With guidance from the Balloon Project Office at the Goddard Space Flight Center Wallops Flight Facility (WFF), two crucial studies were subsequently undertaken in the balloon assembly plants: 1) strength and quality of the film used in fabricating the balloons, and 2) optimization of the film-sealing methods employed. Parallel studies of parameters such as the temperature at which the film becomes brittle were also carried out at both WFF and NSBF. Following the initial intensive testing efforts, a recovery plan was developed and initiated in early 1986. The plan involved five major thrusts: 1) improving the balloon seals by developing seal specifications, optimizing the seals for specific balloon designs, and increasing the monitoring of production seals; 2) near-term material improvement by identifying the most relevant extrusion variables, performing extrusions with different material orientations, and attempting to determine a preferred film orientation using biaxial testing methods; 3) standardizing the balloon designs by limiting the stress index to conservative values (<2500 psi), using only one film thickness, and permitting only two balloon sizes with standard liftoff weights and altitudes, namely 3000 lb to 130,000 ft and 4300 lb to 120,000 ft; 4) conducting a flight-test program of 8–10 flights for each balloon design, ballasting all payloads to meet the fixed standard liftoff weight for the balloon, and carrying science payloads in a piggyback mode on the test flights; and 5) expanding the research and development for research

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Table 1 Characteristics and nominal weights for the standard balloon sizes

Balloon volume, MCF	Balloon weight, lb	Suspended weight, lb	NSBF systems, lb	Nominal altitude, ft in thousands	Flight[a,b] ballast science, lb		Flight[b,c] ballast science, lb	
					10h	12h	20h	36h
12	1710	2100	405	120	220	1475	695	1000
12H	3220	5500	650	100	525	4325	1575	3275
23	3750	4300	600	120	475	3225	1450	2250
28	3355	3000	500	130	375	2125	1150	1350
28H	4555	5500	650	120	600	4250	1825	3025

[a] 10-12-h flight assumes a morning launch. [b] Weights listed are nominal; the maximum and minimum payload weights would vary with the ballast allocation. [c] 20-36-h flight assumes a morning or evening launch.

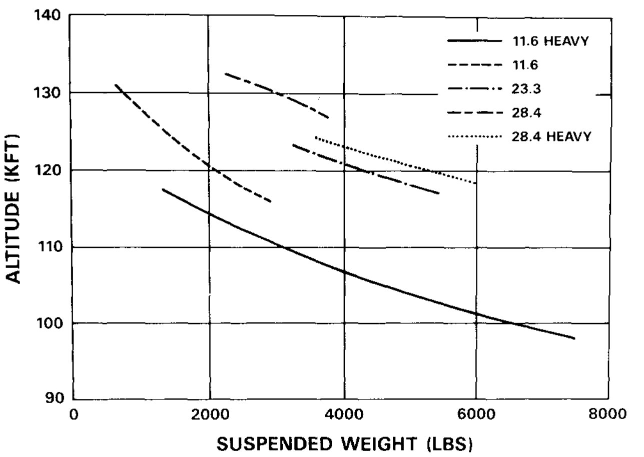

Fig. 1 Dependence of float altitude on suspended weight for the standard balloons.

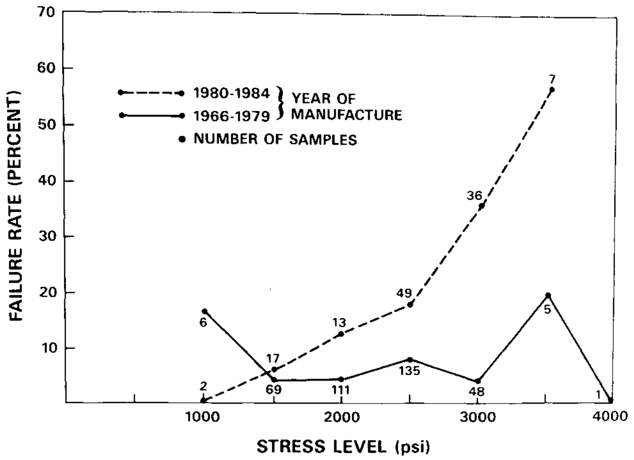

Fig. 2 Dependence of the pre-1985 balloon failures on the calculated stress level.

balloons in the areas of film orientation, balloon shapes, and improved manufacturing methods.

The flight-test program resulted in qualifying balloons manufactured from a new film developed by Raven Industries, Inc., in 1986. More than 75 of these balloons have been flown between May 1986 and June 1989, with only two failures being attributed to the balloons. Two other failures were attributed to operational malfunctions.

Balloons manufactured by Winzen International, Inc., dominated the balloon program before 1985. However, their balloons failed the 1986 flight-test portion of the recovery program, in spite of having passed the prescribed ground tests. As of June 1989, more than 20 balloons made from their newly developed film have been flown without failure.

With the current success rate of more than 100 balloon flights with only two failures attributable to the balloons, and with two independent manufacturers making reliable balloons, the program can be viewed as having achieved unprecedented success.

The ability of the balloon program to respond to scientific demands since its recovery have also been noteworthy. In addition to the routine domestic flights during the past two years, the program has conducted 1) six campaigns to Australia to study the supernova SN1987A, 2) two campaigns to Canada to study low-energy cosmic rays, especially antiprotons, during periods of near-solar-minimum activity, and 3) two long-duration campaigns to support week-long flights from Australia to South America. Previously there had been one foreign campaign every other year, but over the past two years four foreign campaigns per year have been carried out.

The flavor of the current flight activity can be obtained from Table 2, which lists the characteristics of the approximately 50 flights carried out during fiscal year 1988. For each flight, the first and second columns give the NSBF flight number and the date of launch; the third and fourth columns identify the principal investigator and institution; the fifth column identifies the balloon volume; the sixth column lists the suspended liftoff weight (science, ballast, and NSBF-provided equipment); and the seventh and eighth columns show the flight time and float altitude.

Development of Long-Duration Ballooning

The two long-duration campaigns to Australia, one in January-February 1987 and the other in January-February 1988, have shown the feasibility of long-duration balloon flights between Australia and South America. Each campaign consisted of two flights, for a total of four missions. Figure 3 illustrates the approximate trajectories of the flights, which circumnavigated half way around the globe at approximately the latitude of the launch site, Alice Springs, Australia. The flights were terminated and had their payloads recovered in South America, the first in Paraguay and the other three in Brazil. Brazil will be the planned termination area for future semiglobal flights launched from Australia.

The first flight in each long-duration campaign was a passive payload[3,4] that placed minimal requirements on the flight operations. Enough ballast was carried for six day-night transitions, and, with the exception of one night during the second mission, the balloons remained above 110,000 ft for the flight durations, respectively, six and five days in 1987 and 1988. The second flight in each campaign was a much more sophisticated electronic instrument with onboard data recording.[5] Both of those flights experienced ballasting difficulties. The 12-day 1987 flight had all of the ballast dropped during ascent, and the 10-day 1988 flight had its entire ballast dropped before the end of the first week of the mission. The 1988 flight also experienced difficulties with the initial extension of the solar panels, which caused power supply difficulties that affected the tracking of the balloon during part of the flight.

Figures 4 and 5 compare the altitudes of the 1987 flights, which allows a comparison of the performance of ballasted and unballasted flights. The unballasted flights necessarily relied on the RACOON (Radiation Controlled Balloon) flight mode,[6] whereby the balloon was allowed to drop in altitude at

Table 2 Summary of flights carried out in FY 1988

Flight no.	Launch date	Experimenter	Institution	Balloon volume, MCF	Suspend. wt, lb	Time, h	Alt, MB
1454	10/4/87	Traub	SAO	23.3	3450	11.0	4.10
1455	10/10/87	Zander	ULiege	28.4	3036	11.4	3.05
1456	10/13/87	Waters	JPL	23.3	3450	14.9	4.10
1457	10/13/87	Webster	JPL	23.3	3450	21.7	8.06
1458	10/28/87	Bawcom	NSBF	29.4	3000	7.5	2.70
234	10/29/87	Fishman/Sandie	MSFC/LMSC	28.4	3000	43.1	3.05
235	11/8/87	Prince	CalTech	23.3	4300	Abort	
236	11/18/87	Prince	CalTech	23.5	3748	11.5	4.75
237	11/18/87	Murcray	UDenver	11.62	1756	5.5	3.90
238	12/3/87	Bawcom	NSBF	23.5	4300	3.9	4.10
239	12/6/87	Mahoney	JPL	29.47	3000	11.6	3.15
240	12/9/87	Bawcom	NSBF	23.5	4300	3.9	4.45
241	2/8/88	Parnell	MSFC	28.4	3233	124.4	3 to 5
242	2/11/88	Bawcom	NSBF	29.47	3000	4.1	2.90
243	2/16/88	Matteson	UCSD	28.4	3658	199.7	3 to 8
245	4/7/88	Fishman/Sandie	MSFC/LMSC	28.4	3071	41.5	3.05
246	4/11/88	Prince	CalTech	28.4	4695	33.5	5.05
247	4/14/88	White	UCRiverside	23.3	4138	58.4	4.45
248	4/18/88	Cheng	MIT	1.05	1036	12.9	20.00
1459	4/19/88	Sofia	Yale	11.62	1232	8.9	3.95
249	4/30/88	Teegarden	GSFC	28.40	5385	28.5	4.80
1460	5/5/88	Webster	JPL	11.82	3152	26.9	7.90
1461	5/5/88	Zander	Liege	28.4	3119	12.5	3.16
244	5/6/88	Johnson	NRL	29.47	3680	12.5	3.25
1462	5/11/88	Bawcom/Chupp	NSBF/UNH	29.47	3133	14.5	3.15
1463	5/12/88	Traub	SAO	28.4	3756	27.9	3.45
250	5/16/88	Johnson	NRL	28.4	3680	12.5	3.25
251	5/17/88	Grindlay	Harvard	23.3	4013	12.4	4.6
1464	5/25/88	Low	UArizona	2.7	1465	10.1	9.9
1465	6/4/88	Low	UArizona	2.7	1498	12.5	10.0
1467	6/6/88	Murcray	UDenver	11.82	1754	6.5	4.15
1466	6/6/88	Heaps	GSFC	28.4	4900	13.4	4.45
1468	6/18/88	Bawcom	NSBF	29.47	5500	7.4	4.45
1469	7/6/88	Anderson	Harvard	28.4	4500	5.8	4.25
252	7/9/88	Holzworth	UWashington	0.194	75	5.9	9.5
253	7/12/88	Holzworth	UWashington	0.194	76	7.9	9.5
254	7/31/88	Holzworth	UWashington	0.194	74	1.5	N/A
1470	7/31/88	Bawcom	NSBF	29.47	5500	5.1	4.65
1472	8/5/88	Bawcom	NSBF	28.4	5500	4.8	4.66
1473	8/7/88	Anspaugh	JPL	3.49	497	6.0	4.65
1474	8/15/88	Bawcom	NSBF	23.3	4300	5.1	4.29
1475	8/25/88	Mauersberger	UMinnesota	3.8	819	8.0	5.0
255	8/26/88	Schindler	CalTech	23.5	4300	38.5	4.45
256	8/28/88	Binns	UWashington	29.47	3000	25.1	3.85
1476	8/30/88	Lubin	UCSantaBarbra	3.2	2128	13.9	12.0
257	9/4/88	Ahlen	BostonU	28.4	5591	8.9	4.85
1477	9/7/88	Hoops/Bawcom	GSFC/NSBF	28.4	5138	13.2	4.45
1478	9/13/88	Webster	JPL	11.82	3477	24.1	10.0
258	9/30/88	Waters/Bawcom	JPL/NSBF	23.3	3721	27.4	4.0

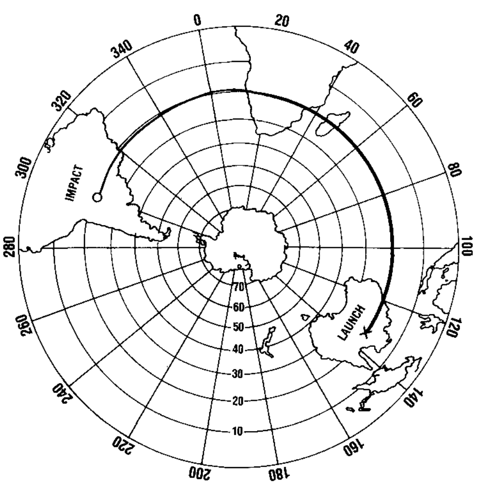

Fig. 3 View from the South Pole of the trajectory of balloons launched from Australia and recovered in South America.

night with the expectation that it would naturally reascend during the day.

A zero-pressure balloon should remain aloft provided the change in temperature of the helium gas in the balloon is less than the change in temperature of the surrounding air. Without appropriate ballasting, the balloon altitude will decline during the transition from day to night as the atmosphere around the balloon cools. If the balloon descends below the tropopause, the minimum temperature region between the troposphere and the stratosphere, it will quickly fall to the Earth's surface. On the other hand, the thermal radiation from the cooling Earth's surface can warm the balloon system so that it remains above the tropopause for substantial periods of time. This tendency can be seen in the altitude profile of the unballasted flight depicted in Fig. 5. Note that zero-pressure balloons also experience significant declines in altitude if the balloon overflies cloud cover such as that associated with an active thunderstorm. This effect was observed a few days into the flight represented in Fig. 5.

Based on the lessons learned during the 1987 and 1988 test campaigns, a focused effort is underway for developing a reli-

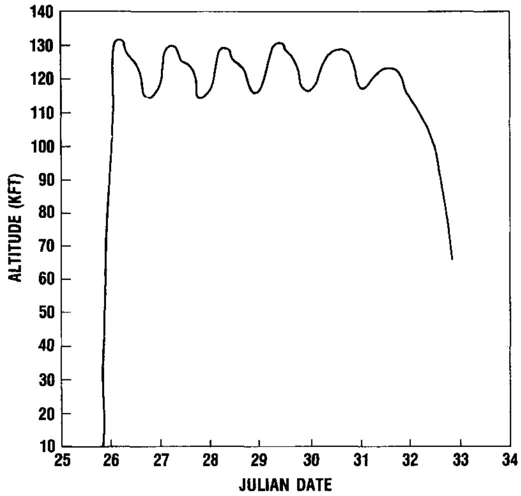

Fig. 4 Altitude profile of ballasted Australia-South America balloon flight.

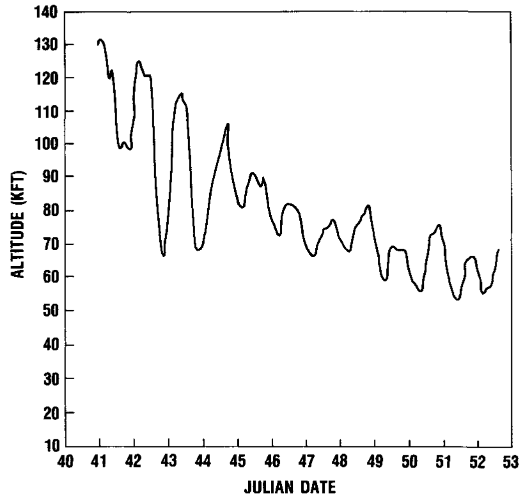

Fig. 5 Altitude profile of unballasted Australia-South American balloon flight.

able long-duration flight support system for global, long-duration flights at both midlatitudes and in Antarctica. The Air Force Geophysical Laboratory conducted a pioneering flight in Antarctica in January of 1988 for a supernova SN1987A investigation.[7] The NASA goal is to support two long-duration campaigns each year with at least two to three flights per campaign initially. The need for stable winds requires that the campaigns be carried out during the local summer season, so the program might support one Southern Hemisphere campaign and one Northern Hemisphere campaign approximately six months apart.

The flight support systems needed for Antarctica and midlatitudes are similar, although there are some crucial differences, e.g., the satellites used for telecommunications would generally be different. For that reason a modular system is being developed. As illustrated schematically in Fig. 6, the generic flight support system consists of the support instrumentation package (SIP) with electronics for controlling the flight, antennas for bidirectional telecommunications, solar panels with rechargeable batteries for power, and a crude (~ 5 deg) pointing capability to ensure that the solar panels will function adequately.

Tests of the long-duration system components will begin in the summer of 1989 using continential U.S. flights. A campaign to Antarctica in December 1989–January 1990 will focus on tests of the long-duration subsystems, as well as the Antarctic launch technique and studies of the wind circulation patterns using four small (~ 0.25 MCF) balloons. The first full-up flight test of the long-duration SIP is planned for the fall of 1990 in the United States. The first system-level Antarctic test should occur during the 1990–91 austral summer.

Both midlatitude and Antarctic long-duration flights offer new research opportunities for all the disciplines served by the balloon program. The time-driver for long-duration development is the so-called Max '91 program, which will focus on studies of the sun during the next period of maximum solar activity (1990–91). The current plan is to have an adequate Antarctic capability in place by December 1991 for the Max '91 investigations, while simultaneously preparing for midlatitude flights. The latter are also in demand for the Max '91 program, especially in the Northern Hemisphere, since ground-based data from observatories in the Northern Hemisphere could be coordinated with the balloon measurements.

The long-duration flights will rely on the 28 MCF two-cap balloon that carries 3000 lb nominal suspended weight to a float altitude of 130,000 ft. For Antarctica, the nominal science weight allocation is 1500 lb, although payload weights up to about 1900 lb could probably be accommodated with sacrifice in altitude. These weight estimates are based on the as-yet-unproven expectation that less ballasting will be required for Antarctic flights because of the continuous daylight during the launch window in the peak of the austral summer. Somewhat lighter science payload weights would be available for midlatitude flights of similar durations and altitudes.

Re-Evaluation of Balloon Flight Safety

The unprecedented success of the balloon program in 1987–88 led to a safety re-evaluation by the WFF Flight Safety Office in 1988. It was hoped that the success with the new balloon films might lead to some reduction in the restrictions on launches from the NSBF in Palestine, Texas. On the contrary, the new calculations have led to even greater restrictions on Palestine launches. In particular, turnaround flights were prohibited in the fall of 1988, and in the future only flights with trajectories to the west (i.e., after the spring turnaround in May and before the fall turnaround in September) will be permitted from Palestine.

Compared with the previous safety analysis in 1984, the 1988 analysis assessed the risk to be 1) about the same for flights within a 150-mile radius of Palestine, 2) dramatically greater for flights extending more than 150 miles to the east of Palestine, and 3) dramatically less for flights extending more than 150 miles to the west of Palestine. Except for the latter

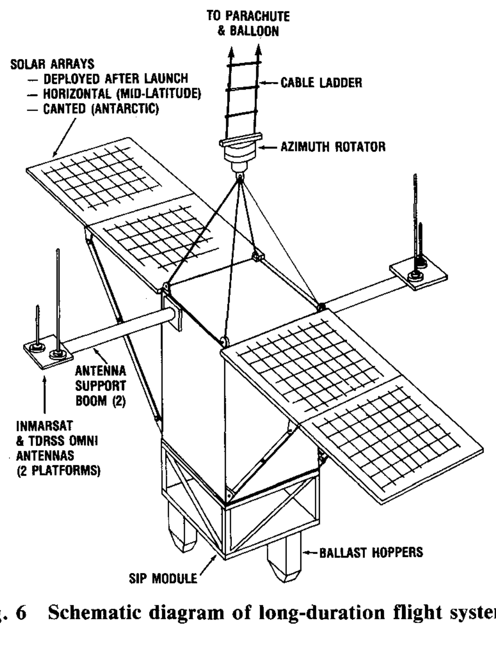

Fig. 6 Schematic diagram of long-duration flight system.

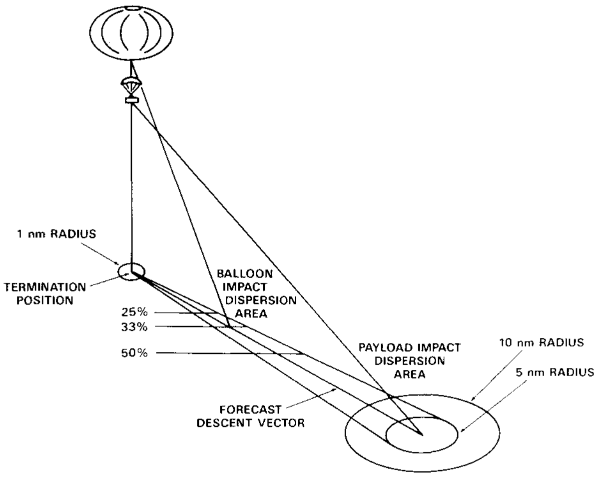

Fig. 7 Schematic diagram of the balloon and payload/parachute descent corridor.

(flights extending more than 150 miles to the west), the calculated risks exceed the accepted maximum casualty expectation, 1×10^{-6}. The risk for turnaround flights was determined to be in excess of the accepted casualty expectation because the wind directions are a priori unknown and variable, and payload impacts would typically occur anywhere within a 300-mile radius of Palestine.

The new restrictions actually result from a better understanding of the risks associated with the flights, and they are derived from the casualty expectation associated with the balloon and payload impacts at the end of a flight. Although the current balloon reliability has greatly reduced the risk involved during the launch phase, by eliminating the catastrophic failures during ascent, it has essentially no effect on the risk during the cut-down/impact phase.

Figure 7 illustrates the cut-down/impact relationships for the two impacting objects, the balloon and the payload/parachute. Their flight path to the ground after flight termination is a function of their weights, the parachute characteristics, and the wind profile in the descent area. The balloon generally impacts about one-third the impact distance of the payload from the termination point. However, due to uncertainties in the wind profile and the position and altitude at flight termination, there is significant dispersion in the actual impacts areas. The calculated descent vector, which predicts the nominal impacts, and the impact dispersion areas define the so-called descent corridor.

Planned flight terminations require that the predicted impact areas are in sparsely populated regions. Cut-downs are not permitted if towns or cities are within the balloon or payload/parachute dispersion areas, typically a radius of 5 n.mi. Furthermore, no large towns are permitted within 10 n.mi. and in some cases up to 20 n.mi. of the projected impact point. Because of the possibility for free fall of the payload, the area directly under the termination point is also considered to be a possible impact point. Although such accidents are rare, a free fall occurred in early June 1989, due to an electronic malfunction that separated the payload from the parachute at float altitude during the middle of the flight.

Air surveillance of the predicted descent corridor is conducted by the tracking aircraft before termination. Furthermore, the tracking aircraft issues the cut-down command and, for the standard daytime cut-downs, visually tracks the payload on the parachute during its descent. The tracking pilot has the authority and capability to prerelease ("pickle") the payload from the parachute if he determines that its continued drift would result in a high risk of either injury to people or major damage to property. Normally, the payload is released from the parachute immediately after impact to reduce the potential damage from the payload being dragged along the ground.

Two major factors in explaining the different casualty expectations from the 1984 and the 1988 safety evaluations are that 1) the population density in the potential impact areas around Palestine, Texas, has increased by about 18%; and 2) the likelihood for the tracking pilot to exercise the pickling option is now considered to be at best 50%, whereas in 1984 it was taken to be about 90%; this option has in fact never been used. These two factors alone have, on average, increased the casualty expectation by about a factor of two for turnaround flights from Palestine.

With the prohibition against turnaround flights from NSBF in Palestine, it has become necessary to alter the mode of operations to include more remote flights. Palestine will, at least for the foreseeable future, remain the base of operations and serve as the staging area for the remote flights. Flights during the period after spring turnaround and before fall turnaround can, of course, still be carried out from Palestine. In practice, however, due to the high-velocity winds in the midsummer, only the first few weeks after spring turnaround and the last few weeks before fall turnaround (when the winds are reasonably slow) offer viable opportunities for most scientific investigations.

In December 1988, Fort Sumner, New Mexico, was designated a semipermanent site for conducting turnaround flights in the western United States, in order to mitigate the loss of Palestine for that purpose. For the past few years, Fort Sumner has served as the remote site for turnaround flights of payloads that exceeded the weight limit for launches from Palestine.

Future Operational Trends

To estimate the requirements to be placed on the program during the next several years, a limited survey of the major discipline offices was carried out in September 1988. Table 3 summarizes the number of flights expected by discipline. The survey indicates that in the future

1) There will be an increase of approximately 50% in the total number of flights requested over the next 3-5 years.

2) There will be an increase in the average requested flight duration (about 90% of the investigators would like >40 h).

3) There will be an increase in the number of investigations requesting long-duration (>1 week) exposures, including solar physics (Max '91 program), cosmic ray physics, and high-energy astrophysics payloads.

4) There will be an increase in the number of investigations requesting exposures from the Southern Hemisphere, including upper-atmosphere research and high-energy astrophysics payloads.

5) There will be an increase in the number of investigations requesting exposures at high latitudes, including ionospheric payloads at the North and South Poles, flights from McMurdo, and flights from Canada.

In addition to these general trends, each discipline has some special requirements. One of the most notable is the need for near-simultaneous flights of complementary payloads for the

Table 3 Projected number of flights over the next several years for the major users

Discipline	FY 89	FY 90	FY 91	FY 92	FY 93
Upper atmosphere	12	14	18	24	24
Astrophysics					
High-energy	8	8	10	14	16
infrared	8	8	10	14	16
Space physics					
Solar	1	3	3	3	2
Ionosphere	4	4	5	5	5
Cosmic	8	8	10	12	14
Total	41	45	56	68	71

Table 4 Strawman flight scenarios capable of meeting the projected flight requirements

Launch window	Number of flights	Location	Comments
Jan.-Feb.	2-3 long dur.	McMurdo/Australia-Brazil New Zealand-Argentina	Southern Hemisphere
Feb.-March	3-4	California-Palestine	Northern Hemisphere
April-May	10-15	Fort Sumner	Turnaround
May-June	3-5	Palestine-New Mexico	E-W (Post turnaround)
June	3-5	Greenville, SC-New Mexico	E-W Summer (40 h)
July	2-3 long dur.	U.S.-China; Sicily-U.S.	Northern Hemisphere
August	4-6	Canada	High geomag. cutoff
Aug.-Sept.	5-10	Palestine-New Mexico	E-W (pre-turnaround)
Sept.-Oct.	10-15	Fort Sumner	Fall turnaround
Nov.-Dec.	3-5	Australia	Southern Hemisphere Low geomag. cutoff
Total	47-76		

upper-atmosphere research investigations. This capability has occasionally been used in the past, but it has not been a standard mode of operations. In the future, it may be necessary to conduct simultaneous flights routinely to meet the total flight requirements.

Table 4 shows a possible scenario that could, in principle, meet most of the currently perceived flight demands over the next 3–5 years. This "strawman" is intended to illustrate how remote operations can be used in conjunction with the NSBF at Palestine and the semipermanent site at Fort Sumner to achieve the flight rate necessary to meet the user requirements. For the sake of illustration, this mission model assumes the existence of remote sites not currently approved, and some that may never be requested. It should be noted that the fall and spring campaigns at the remote locations could be interchanged to achieve an alternative, equally viable mission model.

The most important points to be learned from Table 4 are that 1) scenarios meeting the flight requirements by the science disciplines are possible within the constraints that have been placed on the NSBF site; 2) remote launches are likely to become the operational standard; 3) numerous remote campaigns will place heavy demands on the NSBF launch personnel; and 4) simultaneous launches may be required to meet the science requirements and numbers of launches.

Concluding Remarks

The problems that plagued the balloon program before 1985 seem to have been brought under control. However, since their causes are still not fully understood, vigilance is required to ensure the continued viability of the flight program. Reevaluation of balloon flight safety has led to the loss of the National Scientific Balloon Facility in Palestine, Texas as the prime launch site during the turnaround seasons, which in turn is altering the mode of operations by requiring more remote campaigns. The current flight success rate has also led to increasing demands for longer and more sophisticated flights. Interest in semi- or transglobal flights has grown in the wake of the demonstration of successful flights at both midlatitudes and in Antarctica. Long-duration flights are still in the experimental stage, but with adequate resources and time, they should become routine. Their potential scientific payoff is clearly high, but the problems encountered with both Australia-Brazil and Antarctic flights show the need for a systematic approach to them. Antarctica is especially appealing as a transglobal launch site, both from the standpoint of the unique scientific opportunities it offers and in terms of the low human/property casualty risk. The future demands for scientific launches from either, or both, McMurdo and the South Pole are likely to significantly exceed our near-term capacity to conduct them.

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