# XIV. Flight Experience with Balloons Having Means of Stress Control in the Bubble

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## Abstract

In the recent past a concentrated effort was made to derive solutions to the problem of mid-altitude balloon bursts. Since only a small bubble of the balloon is involved at the time of failure, many of the solutions aim at modifying the stresses in the bubble region alone. Several of the approaches were tried in actual flights and the results are reported.

## 1. INTRODUCTION AND SCOPE

Ever since the advent of the plastic stratosphere balloon, it has been recognized that there is a possibility for random flight failures. Following a fortuitously successful beginning, the percentage of such failures has ranged from a high level during the Korean war, when little was known about materials and balloon design, to comparatively low, tolerable levels. From time to time the failure rate has reverted to moderately high levels which threatened the future of scientific ballooning. The experience of the past 2 years indicates that this is one of those critical periods.

In order to restore and surpass previous levels of reliability, sponsoring agencies and industry have united their efforts to develop improved balloon configurations. These improvements were effected by both material advances and design innovations. The present discussion is limited to the design aspects and does not consider material developments per se.

With the exception of a few ground aborts, which are usually the result of external influences, very nearly all balloon failures occur in the mid-altitudes, on ascent. In most cases the gas bubble at the top of the balloon constitutes only a few percent of the total expanded volume of the balloon. Thus, it seems reasonable to assume that failures can be averted by applying corrective techniques to just the bubble region.

A balloon failure of the type here considered is presumptive evidence of a stress exceeding a material limitation. From this oversimplified theorem we can deduce two general solutions: equalize the stress throughout the available material, or add material to absorb the loading. It is apparent that the material of a conventionally designed balloon can support the load if the load is properly distributed. This is evident since total loading into the balloon is greatest at full inflation, and in this condition failures are virtually unknown.* Concentration of stresses typically occurs in the partially inflated balloon bubble because of its non-symmetrical configuration. In taped balloons this can be a problem because the inelastic tape can prevent the lateral distribution of stresses from gore to gore. In tapeless, semi-cylinder balloons the small fraction of the balloon material which encases the lifting gas can be seriously overloaded while the so-called rope section may have little or no loading. If such anomalies can be eliminated, the resulting distributed load can be readily carried by available material. The second solution ignores the pattern of stresses and simply adds sufficient reinforcement to the critical region to absorb any stresses that occur.

The flight experiences recorded here are limited to balloons having design innovations resulting from the above concepts. It is also limited to those balloon configurations which have been constructed by Raven Industries, Inc. Excluded by this limitation are balloons constructed totally of reinforced materials, and balloons having the Winzen-type polyethylene cap. These are perfectly valid concepts, but they do not fall within the scope of this paper.

The work described, covering the past 1 1/2 years, was sponsored variously by the Air Force Cambridge Research Laboratories, the Office of Naval Research, the National Center for Atmospheric Research, and Raven Industries, Inc.

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*With the exception of rare pressurization failures caused by appendix choking.

## 2. BALLOON CONFIGURATIONS

### 2.1 Stress Distribution or Equalization

Four configurations employing stress-distribution methods were developed and flight tested. Figure 1 shows the basic nature of these designs. First is the tandem or dual balloon which employs a small lift balloon to carry a main balloon to high altitude where at some point the gas from the lift balloon transfers into the main balloon. Gas transfer typically starts at or above the tropopause and is accomplished through the mutual end-fitting which joins the upper and lower envelopes. Such a configuration, it is theorized, will be an improvement over a single cell because the upper balloon applies the vertical stress uniformly into all of the balloon fabric of the main balloon. As gas transfer begins, the main balloon bubble will have an elongated shape and the balloon material should retain a reasonably uniform deployment around the enlarging bubble of gas. A second benefit is that the more rugged lift balloon is designed so that gas transfer occurs above the tropopause and, therefore, the fragile main balloon is carried through this critical region in an uninflated state.

The dome-top balloon, also shown in Figure 1, is not unlike the tandem configuration in that a nearly full top bubble is lifting an unextended main balloon through the atmosphere. In this case, the lift balloon is only half a balloon which is joined at its equator to the main balloon. Here again the dome or half-balloon is designed to be fully distended at an altitude just above the tropopause. By construction, the material of the main balloon is uniformly distributed around the junction of the two shapes. Since the dome is largely deployed at launch, and fully deployed at the tropopause, the main balloon is necessarily very uniformly loaded. Viewing this design in another way, we might say that the dome constitutes a very large end-fitting.

Since the presence of a large, single rope-section is generally considered to be undesirable, it is thought that an advantage can be gained by separating the rope section into several radially symmetrical portions. This may be done by constructing a multiplicity of cells in the bubble section of the balloon, each of which is inflated with an equal share of the lifting gas.

In the compartmented balloon, shown in Figure 1, the cell widths are constructed such that they will become full and start to under-flow at the mid-altitudes. The surplus envelope material between cells will form smaller and evenly distributed rope sections around the bubble.

The SVT design is probably fairly well known by now; however, the principle will be redescribed for those who are not familiar with the concept. The initials stand for Simulated Variable Thickness which refers to the buildup of layers of material between the bubble equator and the top fitting of the balloon. This is roughly equivalent to having a variable-thickness film. The gore pattern is that of a semi-cylinder balloon, while the contour of the seal is that of a fully tailored envelope.

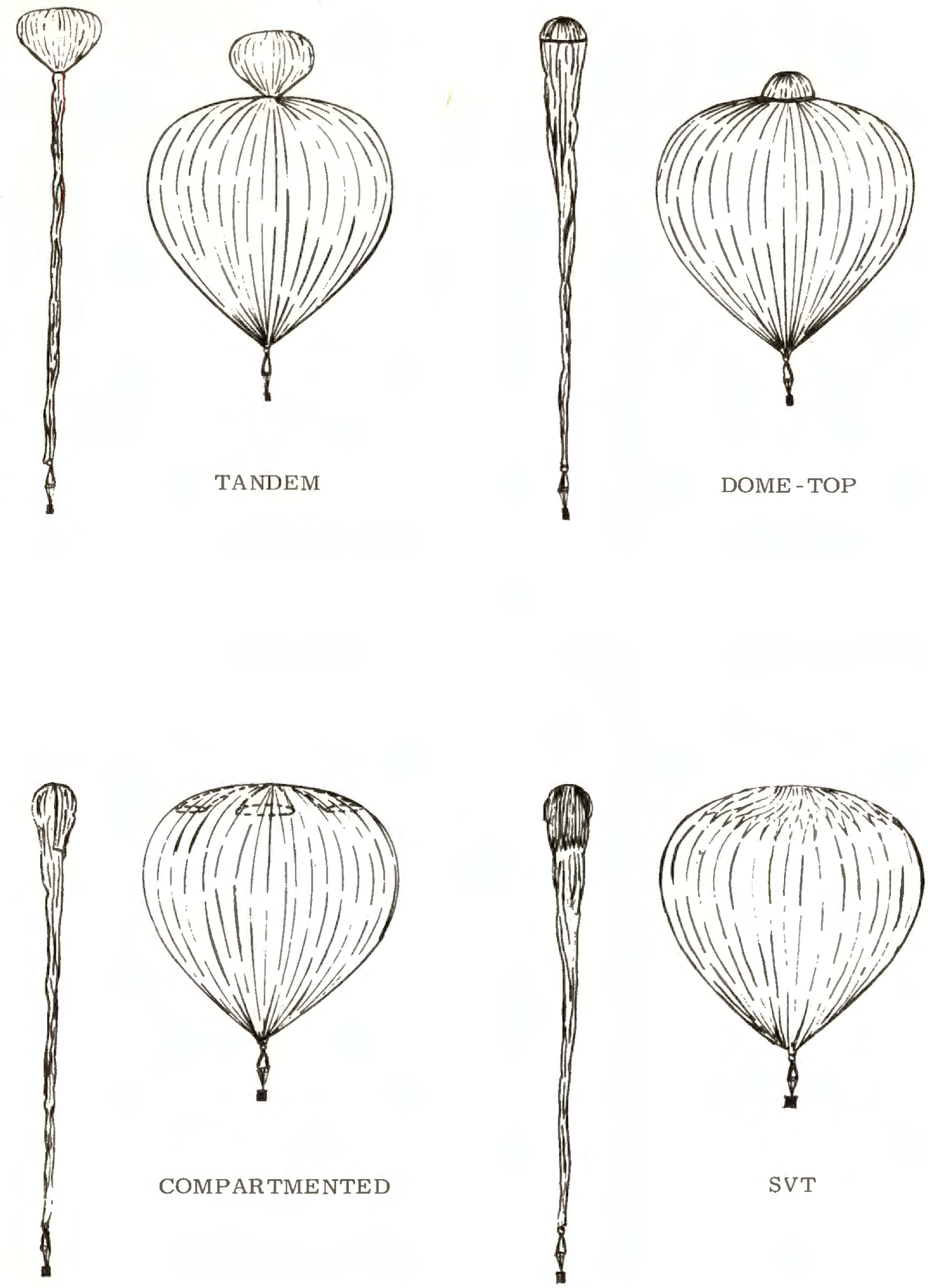


Figure 1. Stress Distribution Means

This design distributes meridional load by bringing much more material into play, as compared with semi-cylinder balloons. In some cases the amount of material under load may be over twice that in a semi-cylinder design. Also, the absence of tapes allows a freer transfer of stresses in lateral or diagonal directions.

### 2.2 Cap Reinforcement

Only one variation of reinforced-cap construction has passed through flight test. Other variations are possible and one is planned for early fabrication. A reinforced cap is defined as an external skin over part of the primary polyethylene balloon envelope. It is usually considered to be of a much stronger material than the basic balloon skin. It may be built up of gore-shaped pieces and attached in a gore-by-gore process, or it may be separately prefabricated and applied as a one-piece overlay. These alternatives are shown in Figure 2.

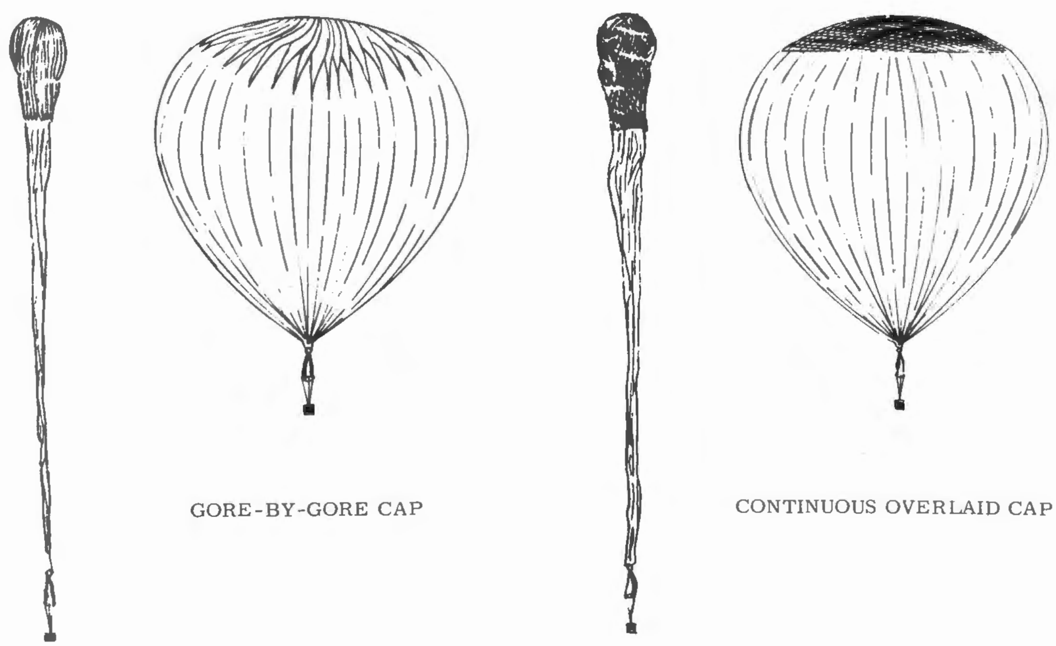


Figure 2. Reinforced Caps

It seems necessary that this cap cover only the region above the bubble equator (when considering its shape at the tropopause). This turns out to be a distance of approximately 70 ft from the top fitting and conveniently includes the entire bubble while the balloon is in the launch platform.

## 3. FLIGHT EXPERIENCE

### 3.1 Tandem Balloon

Four polyethylene balloons of this type were built by Raven and test flown by NCAR at Palestine. All four used a 90,000 cu ft, 1.5 mil, tapeless lift balloon (Figure 3). On two flights the main balloon was a 6 million cu ft, semi-cylinder, 3/4 mil envelope. Both these flights were successful with loads of approximately 340 lb. On the third flight the main balloon was a 9 million cubic footer of 3/4 mil, taped construction. This flight was also successful. The fourth flight employed a 9 million cu ft, 1/2 mil, taped main balloon. On this flight the small lift balloon burst approximately 1 min after the beginning of gas transfer. It was noted that the lift balloon took an unusually oblate shape. These factors are suggestive of a partial choking of the helium transfer tube, although there is no tangible reason to conclude that this is what happened.

The upper balloon is sized so that gas transfer occurs between 40,000 and 42,000 ft altitude. Figure 4 shows the system just after gas transfer has started. In Figure 5, the balloon is at approximately 50,000 ft, and the volume of gas in the main balloon is nearly half of that in the lift balloon. The lift balloon becomes neutrally buoyant at slightly under 100,000 ft, and at the floating altitude (125,000 to 140,000 ft) the residual lift will be only 10 or 20 lb. At this stage the pressure head of gas is the primary force causing the balloon to remain erect. Figure 6 is a view of a 6 million cu ft, 3/4 mil main balloon with the lift balloon partially visible through the skin. The shape apparently indicates the area of contact between the two envelopes. The lift balloon tends to lean over and wobble back and forth during the latter stages of ascent, but this does not appear to be hazardous.

As noted before, one of the supposed advantages of the tandem design is that the polarization and distribution of stresses through the upper part of the main balloon should allow for a greater load capacity. A recent water-model study of this configuration indicated that this may not be true. While the vertical force on the upper end-fitting does tend to cause the main balloon bubble to be somewhat more symmetrical (note Figure 5), a distinct transverse stress occurs in the more bulbous portions of the bubble, which eventually results in rupture at approximately the same total lift as can be obtained without the upper lift balloon. This does not diminish the importance of the other presumed advantage of tandem balloons — that it does carry the main balloon through the tropopause in an uninflated state. This is very probably still a major advantage.

### 3.2 Dome-Top Balloon

Two flights of dome-top balloons were conducted. These were both of 2.69 million cu ft volume and used 3/4 mil film. The first balloon had a 40-ft-diam dome

Figure 3. Tandem Balloon Before Launch

Figure 4. Start of Gas Transfer – 42,000 Ft

Figure 5. Main Balloon Supporting One-Third of Load

Figure 6. Tandem System at Floating Altitude – 130,000 Ft

that was designed to fill out at an altitude of 20,000 ft. This flight failed non-catastrophically shortly after launch. Figure 7 shows a model of this balloon which was used in water-model tests to evaluate the design. Figures 8 and 9 show the first full-scale balloon prior to and during launch at the AFCRL Flight Facility, Chico, California.

In the second balloon, the dome diameter was enlarged to 52 ft, which would theoretically become full at an altitude of 39,000 ft. By visual observation, it appeared that fullness occurred at or near 40,000 ft. This flight, flown on 30 August 1965, was successful. These balloons were both of tapeless construction and carried payloads of 750 lb, well above the tolerable limit for a semi-cylinder tapeless balloon of the same film thickness.

It would be easy to say that "the first of these items was the victim of a learning process and the second is representative of the design." This may or may not be true, but on a statistical basis we cannot presently advance this conclusion. We do definitely have confidence in the concept and expect that this balloon, which we have designated as the Vista Dome design, will find a niche of its own in the diverse requirements of balloon experimentation.

### 3.3 Compartmented Balloons

Two flights with compartmented balloons were flown. The initial flight was made with a 128-ft-diam, 3/4 mil balloon that had four gas cells. This was a good flight through an abnormally cold tropopause and rather high wind shear levels. Symmetry of the bubble can readily be seen in Figure 10. The second flight was made with a modified, 9 million cu ft, 1/2 mil balloon of taped construction. This was left over from a series of ill-fated balloons, and it was felt that if it could be modified by cellular construction and made to fly it would be an acid test of the concept. The balloon did fail at 46,000 ft and thus did not provide the verification.

This is still considered a valid concept, however, and awaits an opportune moment for additional flight evaluation.

### 3.4 SVT Design

Of the various novel balloon configurations discussed, we have by far the largest body of information on the SVT. Our experience consists of 15 flight attempts from which comparative data are obtainable. Three additional balloons were constructed but not flown. There was an even distribution of sizes with five balloons each of nominal 3 million (includes one 2.69 million, see Figure 11), 6 million, and 9 million cubic footers. Eight were of 1/2 mil polyethylene and seven were of 3/4 mil. Aside from these factors, there were, among the total number of 15 balloons, 12 significantly different combinations of construction features. Thus it is very

Figure 7. Model of Dome-Top Balloon

Figure 8. Inflation of Dome Top Balloon at Chico Municipal Airport, Calif.

Figure 9. Dome-Top Balloon at Launch

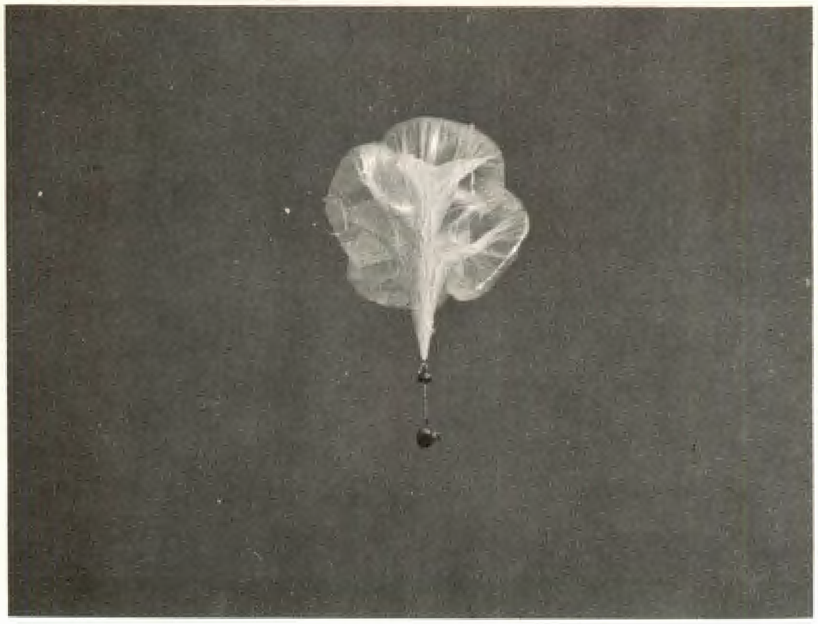

Figure 10. Compartmented Balloon After Launch

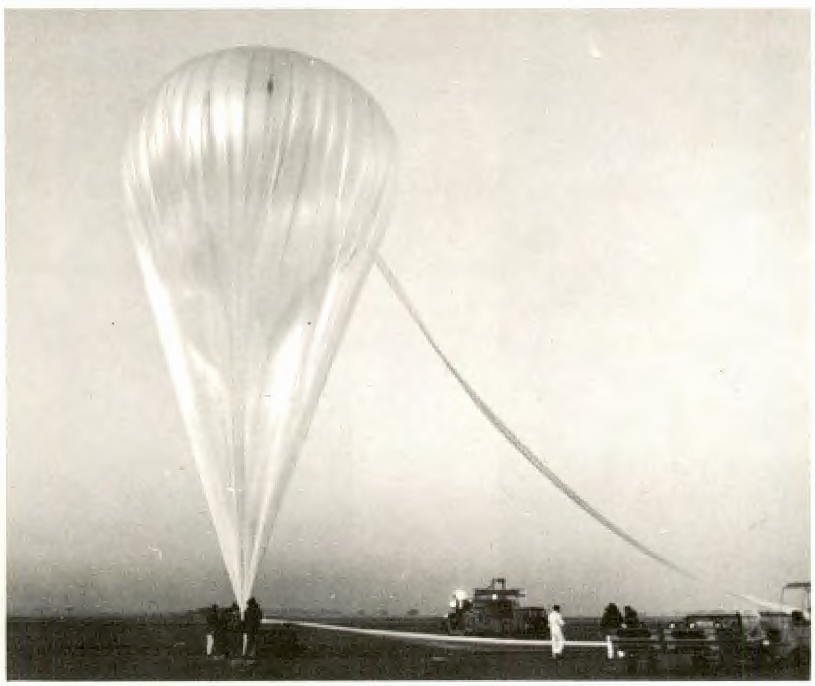

Figure 11. SVT Balloon Inflation

difficult to establish any statistically meaningful figures on success or failure.

The variations in construction include the following:

### 3.4.1 SEALS

Early SVT balloons were fabricated with two different types of sealers; this technique resulted in discontinuous seals that had to be joined end to end. A hot-jet sealer was used in the portion of the contour close to the gore edge, and another type in a region where there was a large amount of flap material outside the seal. In some cases the SVT flap was cut off and the entire balloon sealed in the conventional manner, after which the flap was resealed at its original position. The most recent technique is to use a specially built sealer that can seal from one end of the balloon to the other with no interruptions or discontinuities.

### 3.4.2 END FITTINGS

Two types of end fittings have been used. Most of the earlier flights utilized a 4-in. spool end-fitting, while more recently the EV-13 type of fitting has been favored. It is likely that even larger fittings will be used in the future.

### 3.4.3 FLAP TREATMENT

The external SVT flaps were initially allowed to simply lay over the outside of the balloon, overlapping one another in a natural fashion. Most of the balloons now being built have the flaps attached one-to-another, providing a positive cap over the crown of the balloon.

### 3.4.4 FILM JUNCTURE AT END FITTING

Several lesser variations are involved in the manner used to pleat or arrange the balloon material into the end fitting.

These variations are the natural result of developing a suitable manufacturing technique while retaining the structural concept and attributes of the basic design. One of the variations stands out as clearly undesirable. This is the method of sealing wherein the flap is cut off and resealed after the primary gas seal has been completed. This allowed fabrication with conventional sealing equipment, but involved an undesirable amount of handling.

An analysis of results – though not conclusive – indicates that three of the variations probably have no important effect on reliability. These include the type of sealer or method of sealing (other than the reseal approach described above), the flap treatment, that is, attached or unattached, and the film thickness. Successes occurred as well with one approach as with another.

The first dozen flights or so constitute a prolonged learning process, and the overall flight record to date is not overly impressive (eight successes, seven failures). A study of the variables involved does show that there is one effective combination. All balloons having integral flaps, EV-13 end fittings, and constructed of 1/2 mil film were successful. This constitutes four flights. One 3/4 mil balloon with an integral flap and an EV-13 end fitting failed, but quite apparently for other reasons; it is believed that film thickness is not a dependent variable here. This variation of the design is designated SVT-IV and now has a success ratio of 80 percent.

The flight-test result gives a strong indication that SVT-IV balloons utilizing the new continuous sealer, integral flaps, and large end fittings are superior to semi-cylinder balloons and very competitive with taped balloons.

### 3.5 Strong Cap

Statistically, the strong-cap design has the best flight record. We have demonstrated 100 percent success – in one flight! The balloon involved was of 6 million cu ft volume and constructed of 1/2 mil polyethylene, and the cap material was a 1 1/2 mil thickness of Scotchpak. This cap was of pieced-on construction, assembled gore-by-gore to the balloon. It was made up of wedge-shaped panels that overlapped each other to a distance of 70 ft from the upper end fitting, and then tapered gradually down to a zero width some 20 ft lower. Figure 12 shows this balloon in the launch platform, and Figure 13 is a close-up view of the upper surface of the bubble. The balloon carried a payload of 325 lb and contained a gross lift of 1200 lb. This figure is 70 percent greater than that normally considered safe for 1/2 mil tapeless balloons.

The strong-cap balloon is noticeably more expensive than the previously discussed configurations. It is apparently still considerably less expensive than the light Mylar scrims with which it may be equal in reliability. When normal production status is reached, the following estimate of cost and weight relationships may apply to the various configurations:

| Type of Balloon | Cost Factor | Weight Factor |
|---|---|---|
| Semi-Cylinder, Tapeless | 100% | 100% |
| Tailored Taped | 110-115 | 105-110 |
| Tandem | 120-125 | 115-120 |
| Vista-Dome | 115-120 | 100-105 |
| Compartmented | 115-120 | 110-120 |
| SVT-IV | 110-115 | 100 |
| Strong Cap | 140-160 | 110-120 |

A summary of flight results is presented in Table 1.

The standard, semi-cylinder, tapeless design is used as a basis for comparison. It must be remembered that this design (strong cap) is not suitable over the full range of sizes and loads which apply to other designs. Applicable size range is roughly 3 to 10 million cu ft.

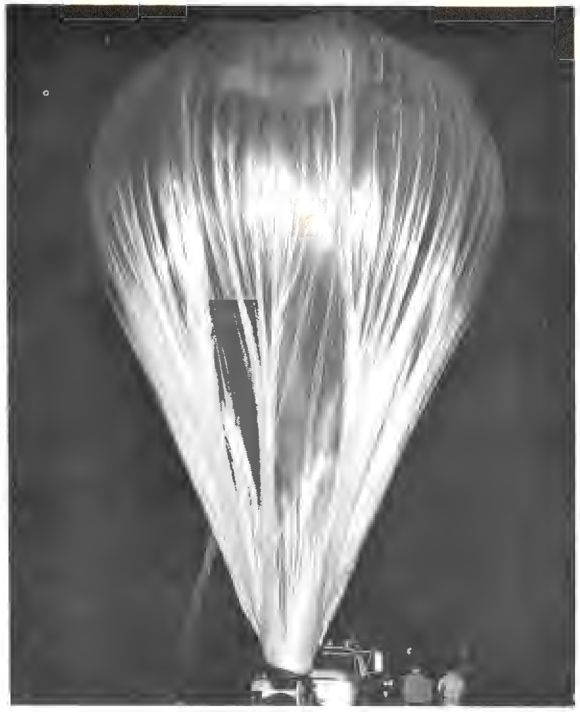

Figure 12. Six-Million Cubic Foot Balloon with Scotchpak Cap

Figure 13. Detail of Scotchpak Cap

Table 1. Flight Results

| Volume (M cu ft) | Film Thickness (mils) | Payload (lb) | Gross Lift (lb) | Comments |
|---|---|---|---|---|
| Tandem Systems | | | | |
| 6.0 + 0.09 | 0.75 + 1.5 | 343 | 1289 | Good flight. Both balloons tapeless. |
| 6.0 + 0.09 | 0.75 + 1.5 | 330 | 1282 | Good flight. Both balloons tapeless. |
| 9.0 + 0.09 | 0.75 + 1.5 | 399 | 1684 | Good flight. Main balloon taped. |
| 9.0 + 0.09 | 0.55 + 1.5 | 439 | 1462 | Lift balloon burst at 42,000 ft. Main balloon taped. |
| Dome – Top | | | | |
| 2.69 | 0.75 | 750 | ≈ 1400 | 40-ft dome. Leak developed at launch. |
| 2.69 | 0.75 | 750 | ≈ 1400 | 52-ft dome. Good flight. |
| Compartmented | | | | |
| 0.8 | 0.75 | 396 | 709 | Good flight thru severe trop. |
| 9.0 | 0.55 | 297 | 1240 | Four-cell construction. Burst at 46,000 ft. |
| SVT | | | | |
| 2.69 | 0.75 | 750 | 1420 | Burst at 52,300 ft. Turbulence noted. |
| 3.0 | 0.55 | 600 | 1080 | Good flight. |
| 3.0 | 0.55 | 334 | 765 | Burst at 36,300 ft. Possible pre-launch damage. |
| 3.0 | 0.55 | 342 | 788 | Good flight. |
| 3.0 | 0.75 | 352 | 881 | Good flight. |
| 6.0 | 0.55 | 316 | 915 | Good flight. |
| 6.0 | 0.55 | 375 | 967 | Good flight. |
| 6.0 | 0.55 | 347 | 991 | Good flight. |
| 6.0 | 0.55 | 274 | 853 | Ground abort. |
| 6.0 | 0.55 | 294 | 878 | Burst at 54,000 ft. |
| 9.0 | 0.75 | 488 | 1469 | Burst at 52,800 ft. |
| 9.0 | 0.75 | 394 | 1468 | Good flight. |
| 9.0 | 0.75 | 478 | 1557 | Burst at 96,000 ft. |
| 9.0 | 0.75 | 437 | 1479 | Slow leaker. Burst at 37,000 ft. |
| 9.0 | 0.75 | unknown | | Good flight. |
| Strong Cap | | | | |
| 6.0 | 0.55 + 1.5 | 325 | 1199 | Good flight. |

## 4. SUMMARY

It cannot be said that the experiences reported give conclusive proof that new levels of balloon reliability have been obtained. Only a continuation of flight programs utilizing these balloon designs will verify this contention. Most of the flights reported were experimental, rather than operational, and the success ratio may be expected to improve in the future.

The choice of a particular design configuration will depend on many factors including payload to be carried, altitude to be attained, film thickness, balloon size, climatic conditions, and, not the least important, cost effectiveness. We believe that with the availability of these several new designs, together with the conventional configurations, such a choice of flight vehicles will allow selection of a type more nearly appropriate to any given set of requirements.

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13. ABSTRACT

The AFCRL Scientific Balloon Workshop was held in September 1965 for the purpose of exchanging information on recent developments in balloon materials, designs, launching techniques, and flight control. In addition to informal meetings of small groups and panel discussions, 13 prepared talks were presented, of which 10 are contained herein. Subjects include: analyses of flight statistics, StratoFilm flight results, methods for testing balloon materials, creep failure theory, tandem balloon systems, and balloon recovery systems.

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