XI. Tandem Balloon Systems

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Abstract

Mission requirements such as low-shock launch, very large heavy-weight payloads, and very large and fragile balloon systems have required development of new launch methods. The tandem balloon system appears to offer the greatest overall advantages with regard to system capability and reliability and balloon recovery. The advantages of this system and areas that require further development are presented.

I. INTRODUCTION

Since there has been considerable interest in tandem balloon systems in the last few years, I'm going to try to give you a little of their history, present some of the major reasons for using the tandem system, and describe a problem unique to tandem launch balloons.

The concept of modern tandem ballooning (in my records) dates back to July 1952 when Ebnetter, at General Mills, Inc., prepared sketches and drawings depicting a tandem system. The drawings described a launch system with a packaged main balloon that deployed from its container when the container was airborne. As far as I know, G.M.I. never did fly the tandem system described.

I believe the first tandem system to be flown was built under an Office of Naval Research contract and flown by Winzen during December 1954. The reports indicate that this tandem system was designed to test a simple launch system, the objective of which was to make feasible the launching of balloon clusters.

The system consisted of a 31-ft-diam, poly launch balloon and a 120-ft-diam main balloon with a gross inflation of 965 lb. The launch went smoothly and the balloon ascended to about 70,000 ft. At this point something happened to the main balloon and the flight terminated. Work was discontinued at this time because of lack of funds.

Not much more was done on tandem systems until 1960 when the Stratoscope II program presented requirements that only a tandem balloon system could meet. Since 1960, considerable effort has been put into tandems.

I think we can divide the recent tandem balloon effort into three areas: (1) that effort derived from the Stratoscope II requirements, (2) that effort by AFCRL, and (3) that effort by the National Center for Atmospheric Research (NCAR). The interest in tandems in these three program areas surely overlaps, but I think the principal concern of each can be described.

2. STRATOSCOPE II PROGRAM

The four principal requirements of the Stratoscope II program which could be fulfilled most easily by a tandem system are:

1. A very high gross lift at launch (7500 lb at the start of the program in 1960, now 16,000 lb).
2. Minimum shock loading to the telescope during launching (0.3G).
3. No horizontal loading to be applied to the telescope framework during the launch.
4. Necessity for afternoon launches requiring inflation during higher-than-normal winds.

In addition, minor requirements were to re-reef the main balloon during descent, and float the reefed system at an altitude where a large helicopter could tow it to a good landing spot.

3. NCAR PROGRAM

The objectives of the NCAR tandem project are:

1. To study deployment of large balloons under more uniformly loaded

conditions... essentially trying to inflate a large balloon without developing a large material rudder.

2. To inflate large balloons above the tropopause where many failures occur.

3. To facilitate balloon inflation under a shelter during adverse weather and then open the shelter, orient the system, and launch the balloon.

4. AFCRL PROGRAM

The AFCRL tandem project has the primary goals of:

1. Facilitating a drop-sleeve reefing system to allow recovery and reuse of expensive balloons (as Mr. J. Payne described yesterday).

2. Providing a system to launch very large balloons made of the lightweight materials that will be designed for an altitude of 175, 000 to 180, 000 ft. The launch balloons on these systems would be disconnected at an altitude where they are no longer useful.

All of the primary goals of the three program areas were met with a high degree of success. Most of them have been, or will be, reported individually.

The following figures depict three tandem balloon launch techniques, each of which is somewhat different.

In Figure 1, the stratoscope main balloon is left in the box. The launch balloon is laid out and a donut is installed about 45 ft from the top. The donut is a padded steel hoop. Its purpose is to keep the balloon reefing sleeve from tearing beneath the inflated bubble, and letting uninflated material sail in the wind. As the inflation continues (Figure 2), the donut is slid down and the reefing sleeve opens above it. When the donut reaches the bottom, the launch balloon has approximately 4000 lb of lift in it and is quite stable. The donut is removed as the inflation continues.

As the inflation is completed, the telescope is attached to the system. The main balloon is pulled out of its box as the launch balloon is let up by a winch vehicle. The erected flight train is pulled sideways about 15 deg into the wind. The cable is then released, the flight train travels with the wind, and when the entire system is vertical the telescope is released from its anchor vehicle and is picked up vertically with very little launch shock. The system ascends (Figure 3), with the main balloon inflation beginning about 7000 ft. This system has had eight successful flights so far.

The AFCRL heavy-load tandem system, which incorporates a recovery reefing sleeve, is shown laid out in Figure 4. Both the launch balloon and the main balloon are extended full length on the ground. Again a reefing sleeve and donut are used to aid initial inflation of the launch balloon (Figure 4).

In this case the donut is a torrus of balloon material put on the balloon prior to inflation; the torrus is restrained in the down-wind direction by a ground vehicle.

If it begins to slide down too far, tension on the line is increased to hold it in place (Figure 5).

The reefing sleeve tears open above the torrus as the balloon inflates (Figure 6). When the torrus reaches bottom, it is removed by cutting it in two (Figure 7).

In Figure 8, the main balloon laid out on the ground is erected through a large arc by the winch vehicle. When the balloon is erect, the anchor cable is released and the payload is picked up (Figure 9). The system ascends with gas transfer starting at about 10,000 ft (Figure 10). Figure 11 shows the outline of the tandem balloon floating with both balloons inflated. There have been two of these flights.

The NCAR launch system can hardly be differentiated from a standard dynamic launch. The launch balloon is inflated under the launch arm and released in the normal fashion. One main difference is that, upon release, the main balloon does not sail as it picks up from the ground as is normally witnessed in a dynamic launch.

Figure 12 shows an analysis of the internal forces developed in the launch balloon of a heavy-load tandem balloon system.

The object of the exercise displayed in Figure 12 is to determine the material loading in the launch balloon. To find the material loading we apply a load beneath the launch balloon as increased by the cone angle of the balloon and divide this by the inches of balloon material carrying the load.

The problem is to find the cone angle of the launch balloon. The cone angle is a result of the pressure head acting on the base of the balloon. This head consists of two parts: (1) the static or standpipe head of helium in the main balloon, and (2) the dynamic head resulting from the back pressure of pumping the expanding helium into the main balloon.

Contributing factors are the volume change of the launch balloon as the cone angle increases; the volume change of the launch balloon as the increasing load elongates the launch balloon gore length; the decrease in load in the launch balloon as it rises and transfers helium to the main balloon; and the rate of rise which affects the gas transfer rate.

By a process of estimation, calculation, and iteration, the group of curves shown in Figure 12 is determined.

Looking at Figure 12 we see that as the balloon rises the helium head and thus the cone angle increases. This combined with a decrease in lift in the launch balloon results in a material loading of about 7 lb/in. at launch, 12 lb/in. at about 12,000 ft altitude, or a decrease to about 2 or 3 lb/in. at the 80,000-ft float altitude.

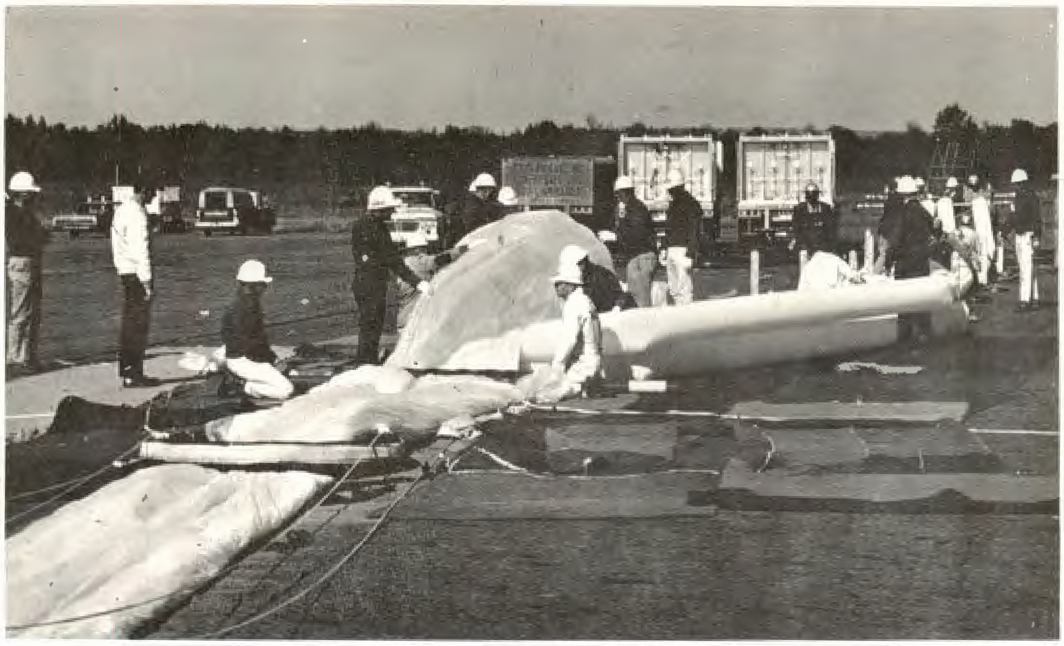

Figure 1. Start of Stratoscope Inflation

Figure 2. Stratoscope Inflation

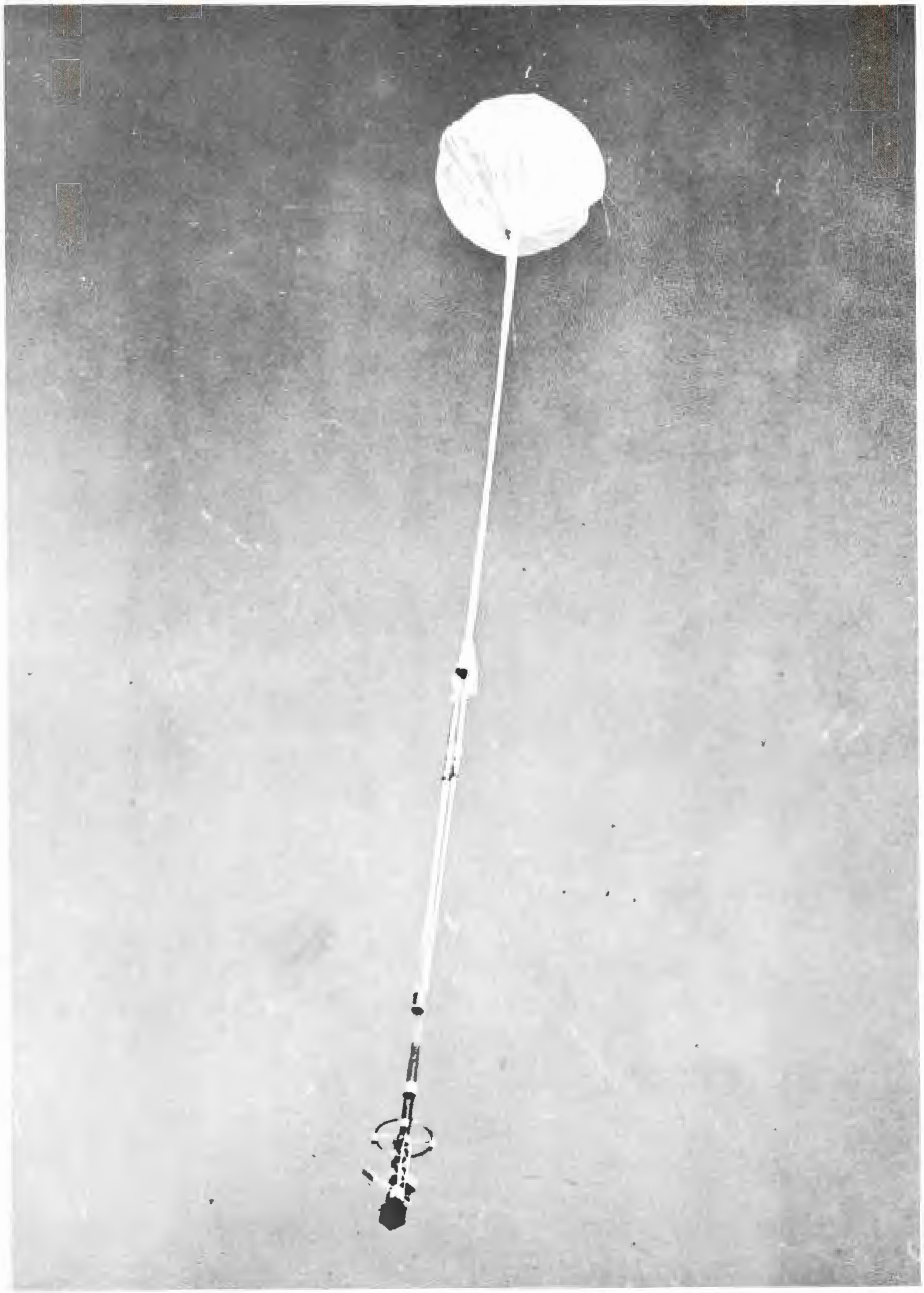

Figure 3. Stratoscope II System, Ascending from the Launch Pad

Figure 4. AFCRL Inflation Torrus

Figure 5. AFCRL Launch Balloon Inflation

Figure 6. Continued Launch Balloon Inflation

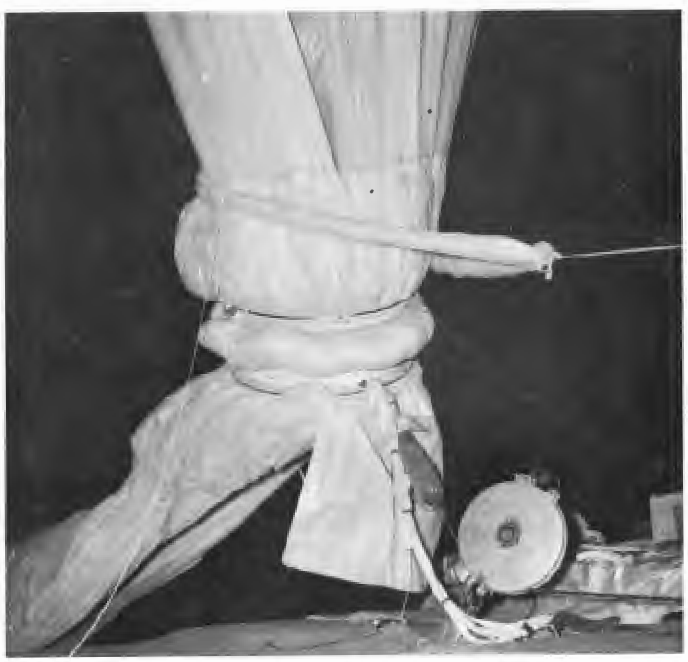

Figure 7. Inflation Completed

Figure 8. Tandem System Reel-Up

Figure 9. Release Anchor Cable

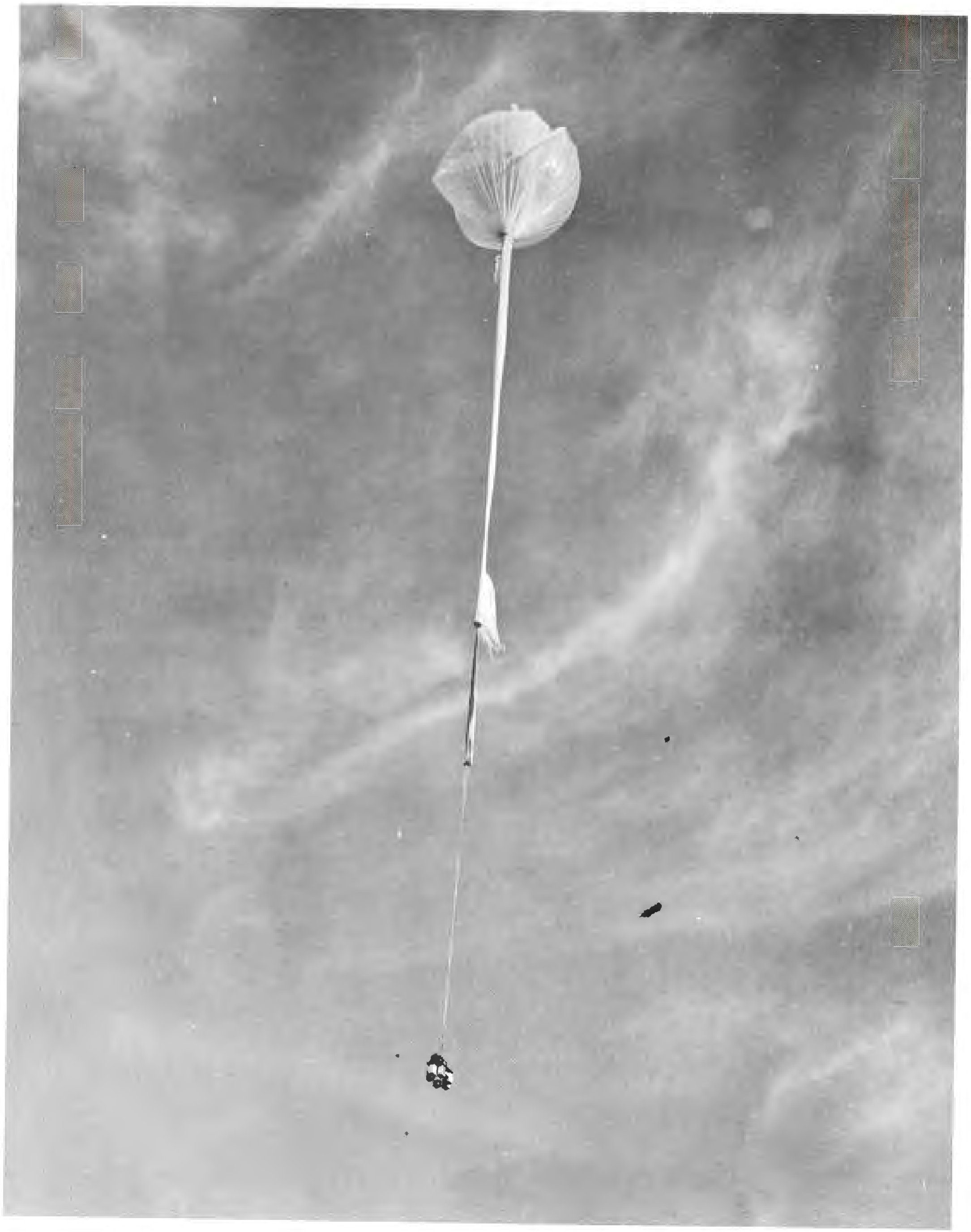

Figure 10. Ascending Flight System

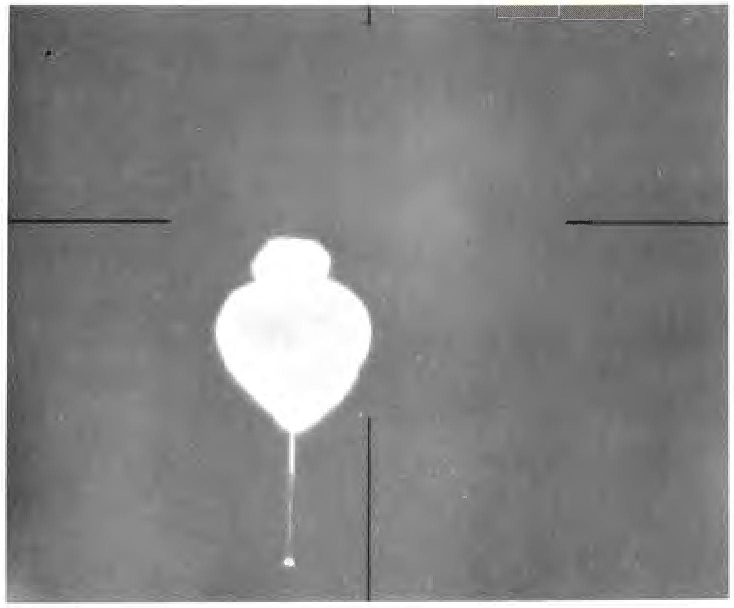

Figure 11. Tandem System at Floating Altitude

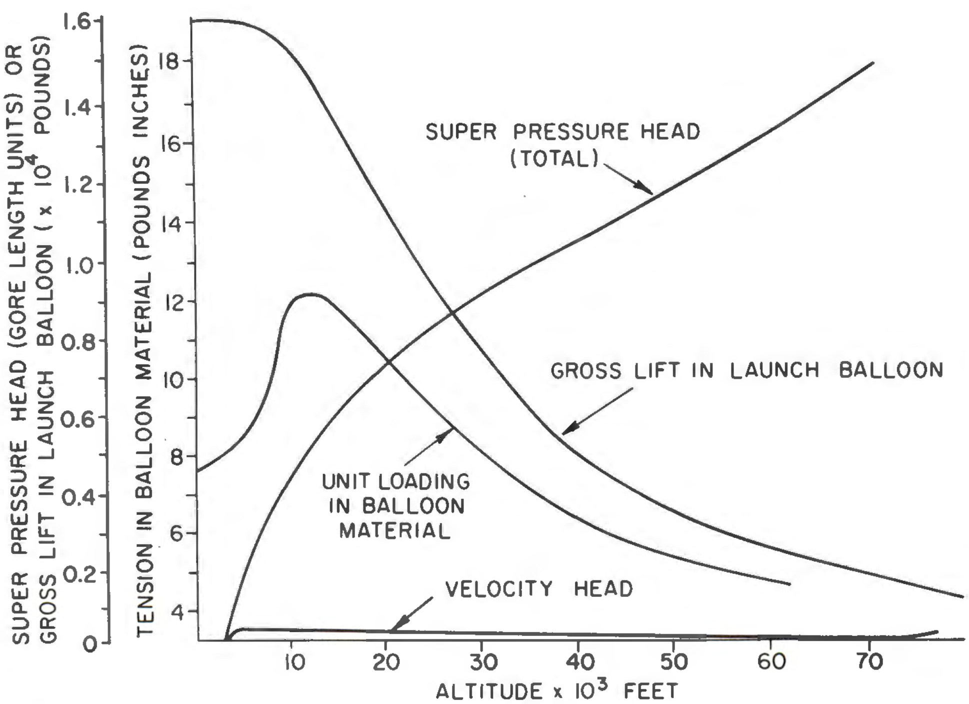

Figure 12. Stratoscope II Launch Balloon