CHAPTER 4

TESTING BALLOONSATS

The near space environment and flight into near space are difficult at times, and the BalloonSat must function properly in this environment, without losing parts or being difficult to launch. The six performance tests described in this chapter simulate many of the aspects of the near space mission. By successfully completing them, the BalloonSat Program Manager can be confident that each BalloonSats will be successful. However, since the BalloonSat Program Manager must accept the risks associated with the BalloonSat launch, they must decide to accept or modify the standards for each test.

Some of these tests are not appropriate rejecting a BalloonSat for the mission. Instead, they provide evidence for needed improvement. In addition, the BalloonSat Program Manager can use the results of these tests to generate a score for BalloonSat Team evaluations. The recommended six tests are Weight, Functional, Thermal, Drop, Shake, and Prep.

4.1 WEIGHT TEST

One requirement for the BalloonSat Program Manager is to give several requirements that each BalloonSat must meet. The maximum allowable weight for each BalloonSat is one of them. Therefore, during construction, each BalloonSat Team should be weighing their creation. The final results of the weight test should not surprise any of the BalloonSat teams.

4.1.1 Weight Test Background

Since the Federal Aviation Administration imposes weight limits to untethered balloon flights, the combined weight of the mission's BalloonSats is limited. To be equitable about this requirement, the total available payload weight for the missions is divided equally amount the BalloonSats.

4.1.2 Weight Test Procedure

Use an inexpensive digital hobby scale for this test.

- Load each BalloonSat with its internal experiments, including batteries
- Seal the BalloonSat hatch with rubber bands
- Record the weight of each BalloonSat in writing

Pass Criteria

- Any BalloonSat weighing less than the allowed maximum is ready for the next test.

Note: The traditional maximum weight allowed for BalloonSats is 450 grams (one pound). BalloonSat teams should be encouraged to create the lightest weight BalloonSat capable of carrying out the most science by developing a scoring system that grants higher scores to lower weights.

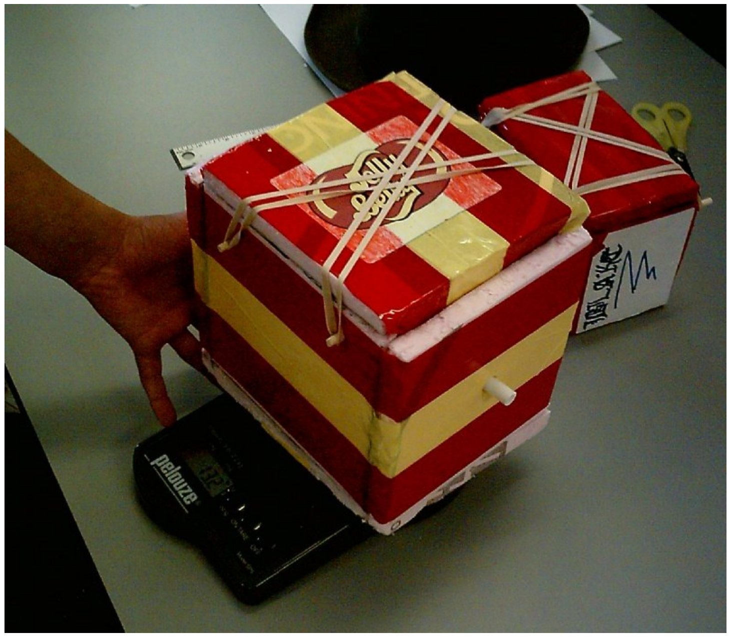

FIGURE 4-1. A middle school student weighing his BalloonSat.

4.2 FUNCTIONAL TESTING

Functional testing ensures the BalloonSat is capable of carrying out its mission. Because of the costs associated with a near space launch, it's not justified to launch a BalloonSat with a high risk of functional failure.

4.2.1 Functional Testing Background

The costs associated with a near space launch can be broken into three categories, risk, flight, and time.

Risk Cost

On every near space mission, there's a small risk that the near spacecraft will get lost. Redundant back-up trackers onboard the near spacecraft mitigate, but do not eliminate, this risk. If the trackers should fail, the predicted flight path has significant error, and the recovery zone is located in a desolate or low populated region, may prevent the return of the near spacecraft. A near spacecraft consisting of just two independent APRS trackers can cost over $300.

Not only does the owner of the near spacecraft face this risk, so does the BalloonSat Program Manager who purchased the items to construct the BalloonSat. The cost of a BalloonSat can approach $100.

Flight Costs

To carry out a near space mission typically requires a $60 weather balloon and $100 worth of helium. An additional cost is the gasoline for the launch and chase crew. Including the driving to the launch site, possibly four hours of chase and recovery time, and driving home, chase crews may drive over 160 kilometers (100 miles). In all likelihood, the chase vehicle is capable of off-road driving and probably has poor gas mileage.

Time Cost

Not all costs relate to money, the time spent planning, launching, and recovering a near space mission can be substantial. The launch crew will spend at least two hours prior to the launch preparing for the flight and making predictions. An hour or more of traveling to the launch site may be necessary, depending on wind conditions. To fill a balloon and launch the near spacecraft requires at a minimum of one hour. Three or four hours may be necessary to chase and recover the near spacecraft and its payload of BalloonSats. Then chase crews must drive home. All told, launch crews will spend at least nine hours in support of the mission.

Combining these costs together and dividing them among five BalloonSats, we see each BalloonSat requires approximately $135 in cost, 1.5 hours of time, and a share of the risk that a $300 near spacecraft could be lost. These costs and risks are acceptable, if, the BalloonSat has a high probability of functioning properly for the duration of the mission. Therefore, the Functional Test is designed to verify each BalloonSat is capable of collecting its data for the duration of a typical mission (pre-launch to touchdown).

4.2.2 Functional Testing Procedure

- Program the datalogger and prep all experiments like cameras
- Load the BalloonSat with its batteries, programmed avionics, and experiments
- Start the BalloonSat and let it sit for three hours
- Review the data collected

Pass Criteria
- Did the experiments record data for the entire three hours?
- Did the experiments record the expected data?
- Did the camera have an unobstructed field of view?

4.3 THERMAL TESTING

The air temperature in near space can drop as low as -68 degrees C (-90 degrees F). That’s a temperature that most items (snowmen being an exception) don’t like.

4.3.1 Thermal Testing Background

Some electronics, like dataloggers, have minimum recommended temperatures. Levels for most industrial items range from -40 degrees C to +85 degrees C (-40 degrees F to 185 degrees F).

As the temperature of a material drops, so does it molecular activity. This is a factor for batteries, which are chemical devices that produce a voltage based on their internal chemical reactions. So as its temperature drops, its ability to produce voltage under a given load decreases. Therefore, batteries have minimum rated temperature. Going below this temperature risks the battery will fail to function

TABLE 4-1. Minimum Recommended Battery Temperatures

Battery Chemistry	Minimum Temperature
Alkaline	-18 degrees C (0 degrees F)
NiCd/NiMH	-20 degrees C (-4 degrees F)
Lithium	-55 degrees C (-67 degrees F)

4.3.2 Thermal Testing Procedure

A thermal test requires a thermal test chamber. Therefore, construct the thermal test chamber (TTC) as explained in Appendix A.

FIGURE 4-2. Loading a BalloonSat into a thermal test chamber.

● Charge the chamber with dry ice and let it chill
● Measure the internal temperature and record
● Program one or more temperature sensors
● Load a temperature sensor into each BalloonSat
● Load the BalloonSats inside the chamber and close the lid
● Let the BalloonSats set for 30 minutes
● Remove them and download their temperature data
● Evaluate temperature data

Pass Criteria
● How fast did each BalloonSat cool
● How cold did each BalloonSat ultimately get

Note: Thirty minutes is probably long enough to let the thermal test chamber cool before beginning the test. More than one BalloonSat can fit inside the thermal test chamber, so prepare more than one datalogger. The slower a BalloonSat cools, the better. In addition, the warmer the BalloonSat remains at the end of the test, the better. Unless an item inside a BalloonSat is severely temperature sensitive, the thermal test is not necessary or sufficient reason to prohibit a BalloonSat from flying. However, each BalloonSat can receive a score based on the above criterion.

4.4 DROP TESTING

Landing can be a violent experience, even with a parachute. Therefore, it's important to verify that a BalloonSat will not break apart upon touchdown and lose its internal experiments.

4.4.1 Drop Testing Background

At touchdown, BalloonSats can descend at a speed of 16 kilometers per hour (kmph) or 10 miles per hour (mph). That's equal to 4.5 meters per second (m/s) or 14.7 feet per second (ft/s). We can simulate the parachute landing by dropping the BalloonSat. As the BalloonSat (or any other mass) accelerates under the force of gravity its speed increases according to the following formula.

$$\mathbf{v = at}$$

This formula assumes that no forces, like air drag, act on the falling body. For our needs, this is an acceptable assumption. In this equation, **v** is velocity (or speed in our case), **a** is the acceleration of gravity (9.8 m/s^2 or 32.2 ft/s^2), and **t** is the time (in units of seconds). The calculated speed will be in units of m/s or ft/s.

Rearranging the equation, we can see that the time necessary to reach the touchdown speed of a parachute is given by,

$$\mathbf{t = v/a}$$

Solving the above equation, we find the BalloonSat must fall for 0.5 seconds. The drop test is easier to perform if we know how high to drop the BalloonSat rather than for how long. The distance the BalloonSat will fall in a given time is given by the formula below.

$$d = \frac{1}{2} at^2$$

This formula also assumes no other forces are acting on the falling BalloonSat. Solving for distance (d), we find the BalloonSat falls 1.2 m (4.0 ft) in 0.5 seconds. However, we don't want a BalloonSat just to survive a drop at the predicted speed. We want it to survive the drop with some reserve. Unlike the aerospace industry, we cannot make multiple copies of the same flight article (BalloonSat) for testing. At the same time, we can't test the BalloonSat to destruction. The minimum landing speed for the drop test is an issue for the BalloonSat Program Manager to decide, however this chapter does recommend three options below.

Aside from the drop height and number of drops for each BalloonSat, the landing surface and BalloonSat orientation are two additional factors to consider for the drop test. Recovery normally occurs in open fields and rarely on roads. Therefore, an acceptable compromise between a hard floor and shag carpet must be found to drop the BalloonSat over. The attitude, or orientation, of the BalloonSat at recovery is unpredictable. That's because during the descent, BalloonSats may tangle with each other, may possibly tangle with the burst balloon, or travel horizontally during the descent.

4.4.2 Drop Test Procedure

FIGURE 4-3. A BalloonSat being readied for its drop test.

● Load up the BalloonSat with its experiments and battery and close its hatch
● Lift each BalloonSat to the height selected by the BalloonSat Program Manager
● Orient the BalloonSat bottom down
● Drop each BalloonSat the same number of times

Pass Criteria
● Did the BalloonSat remain sealed
● Did the BalloonSat remain in one piece

Note: The drop test requires the use of a ladder. Do not use chairs for this test, as they aren't as safe. Always have a second person steady the ladder when someone climbs it for the drop test. Place a small rug below the ladder as the recovery zone for each drop test. Table 4-2 lists several recommended drop heights, based on landing speed criteria

TABLE 4-2. Drop Heights

Descent Speed	50% faster	100% faster
1.2 m (4.0 ft)	2.8 m (9.0 ft)	4.1 m (13.6 ft)

The number of times to drop each BalloonSat depends on the landing speed of the BalloonSat. One recommendation is to drop BalloonSats three times at descent speed, twice at a 50% faster, and only once at a 100% faster. Don't try to prevent the BalloonSat from tumbling.

4.5 SHAKE TESTING

The initial launch and subsequent descent of a BalloonSat is a time of rapid changes in motion in three dimensions. Since the BalloonSat is inaccessible after launch, the shaking it experiences at launch cannot shift the position of internal components in ways harmful to the completion of the mission. It's also preferred that motion during the descent doesn't shift the internal configuration of the BalloonSat either, as there may be important data collected during the descent.

4.5.1 Shake Test Background

According to accelerometers carried on near space flights, momentary accelerations in excess of three g's are possible during the most violent part of the mission, balloon burst and the initial descent. However, for the majority of the ascent, accelerations tend to be below 0.25 g's.

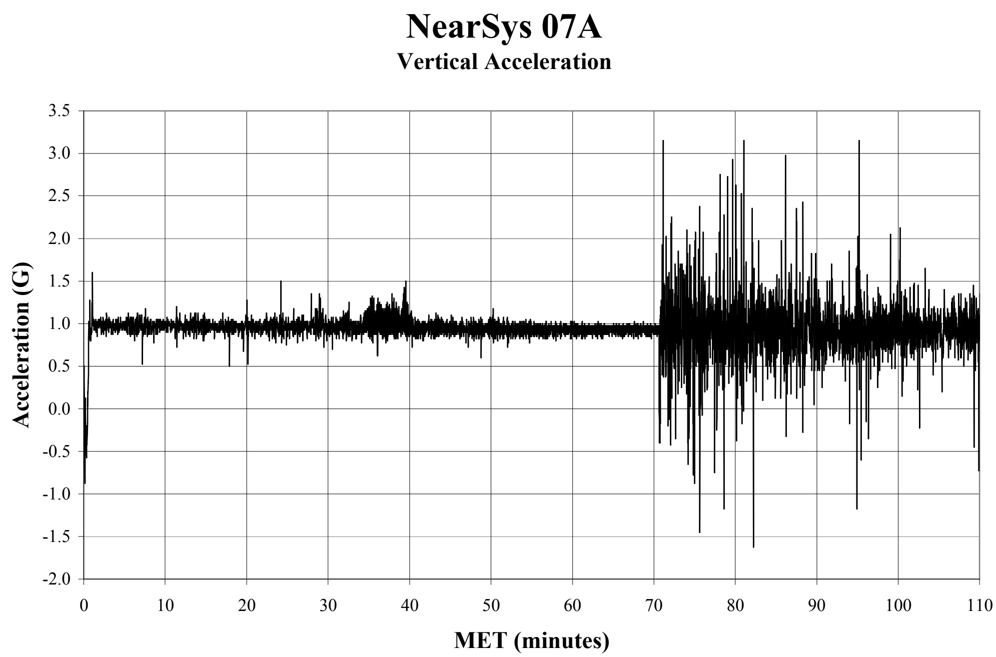

FIGURE 4-4. Typical acceleration of a near space flight.

Figure 4-4 illustrates that for the majority of the mission, a BalloonSat doesn't experience much shaking. The first violent encounter a BalloonSat experiences is the launch. If its internal components shake loose or shift at this time, it's possible some of its experiments will fail to return proper data. A BalloonSat's most violent experience is balloon burst, which occurs at an altitude around 85,000 feet. If a BalloonSat breaks up at this altitude, its internal components will scatter over a wide region and are unlikely to be located again. Therefore, it is crucial that the BalloonSat crew test their creation for its ability to stand up to the rigors of the launch, balloon burst, and its initial descent.

4.5.2 Shake Test Procedure

The shake test is a two stage test of a BalloonSat.

- Load the BalloonSat with its contents
- Seal the BalloonSat hatch with rubber bands
- Rotate the BalloonSat rapidly about three perpendicular axes, one axis at a time

Pass Criteria

- Were loose parts heard rattling around?

Second stage requires the use of a shake stick

- Load the BalloonSat with its contents
- Seal the BalloonSat hatch with rubber bands
- Load all items inside the BalloonSat

● Seal its hatch with rubber bands
● Pass the shake stick cords through the BalloonSat's suspension tubes
● Lock the BalloonSat onto the shake stick with split rings
● Climb the step ladder and wear eye and/or face protection
● Hold onto the step ladder and begin shaking the BalloonSat severely
● Shake each BalloonSat for the same length of time
● Remove the BalloonSat from the shake stick

Pass Criteria
● Gently shake the BalloonSat listening for the rattling of loose items
● Open the BalloonSat and inspect its interior

Note: The second stage of the shake test simulates the effects of balloon burst and initial descent on the BalloonSat. Shake the BalloonSat by snapping the shake stick cords, but don't batter the BalloonSat with the shake stick's wooden dowel. The BalloonSat Program Manager determines the minimum time the tester should shake the BalloonSat. However, five minutes of severe shaking should suffice. Safety glasses or face shield are required to perform the shake test on a BalloonSat.

The Shake Stick

The shake stick is a long wooden dowel with two holes drilled through it. Position the holes about 15 cm (6 inches) apart near one end of the dowel. Pass two Spectra or nylon cords (about one meter or one yard long) through the holes and tie their centers together in an overhand knot with roughly equal lengths of cord hanging from the knots. Before passing and tying the cords, heat their cut ends to melt them so they do not fray. Tie small bearing swivels to the four ends of the dangling cords the free end of each cord in a doubled up, overhand knot. The cords now simulate the suspension lines that connect the BalloonSat to the near spacecraft. As in a near space mission, the cords pass through the BalloonSat's suspension tubes. A split ring links together the swivels at the end of the cords to prevent the BalloonSat from slipping off while being shaken.

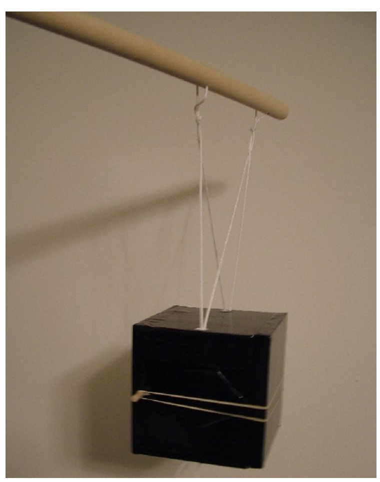

FIGURE 4-5. A BalloonSat undergoing a shake test.

4.6 PREP TESTING

The available free time during a launch is limited, as are the available tools, and perhaps even a comfortable climate.

4.6.1 Prep Testing Background

A weather balloon is not a structure capable of surviving moderate wind loads on the ground. In flight, it's a different matter, as a balloon is free to move with the wind, however, that's not the case on the ground while the launch team fills a balloon from a stationary filling station. When the winds blow too strongly, the balloon risks being blown into the ground or creating string burns in the hands of its wranglers.

As a result, the balloon filling normally takes place in early morning before surface winds have a chance to pick up. Since little time is available to the teams of each BalloonSat, it's important that they be able to prepare (prep) their BalloonSat rapidly.

In addition, the amount of specialty tools available at the launch site is limit. Therefore, a BalloonSat's design must allow its crew to prep with a minimal of tools. This is one reason that the BalloonSat Principia recommends designing BalloonSats with hatches closed with rubber bands.

It can be cold on the morning of a BalloonSat launch. If this is the case, then the BalloonSat design should allow gloved crews to prep it for launch.

4.6.2 Prep Testing Procedure

- Configure each BalloonSat for the condition they will arrive to the launch site
- Layout any tools the BalloonSat team will need
- Call begin and start a stop watch at the same time
- Record the time needed to prep and close the BalloonSat

Pass Criteria

- Did the launch team prep and close out the BalloonSat within the allotted time?

Note: The battery is not usually loaded in the BalloonSat before, as it protects the battery from accidental discharge before the mission begins. No other members of the BalloonSat team are to communicate with the launch team during this test. The time limit for this test is flexible, and unless the prep time is excessive, this test is not justification to prevent a BalloonSat team from launching their project. Results from this test can identify launch crew that need practice prepping their BalloonSat. If the launch is to take place during cold weather, the launch team should demonstrate that most if not all of the checklist can be completed while wearing gloves.

4.7 Test Conclusion

These tests evaluate a BalloonSat's ability to survive the rigors of a near space flight. BalloonSats exceeding their maximum allowable weight, not functioning as designed, and suffering excessive damage during drops or shaking should be modified and retested. While tests like thermal and prep can be justification for modification, the tests are more effective as challenges for BalloonSat teams and useful for creating a score for each team.