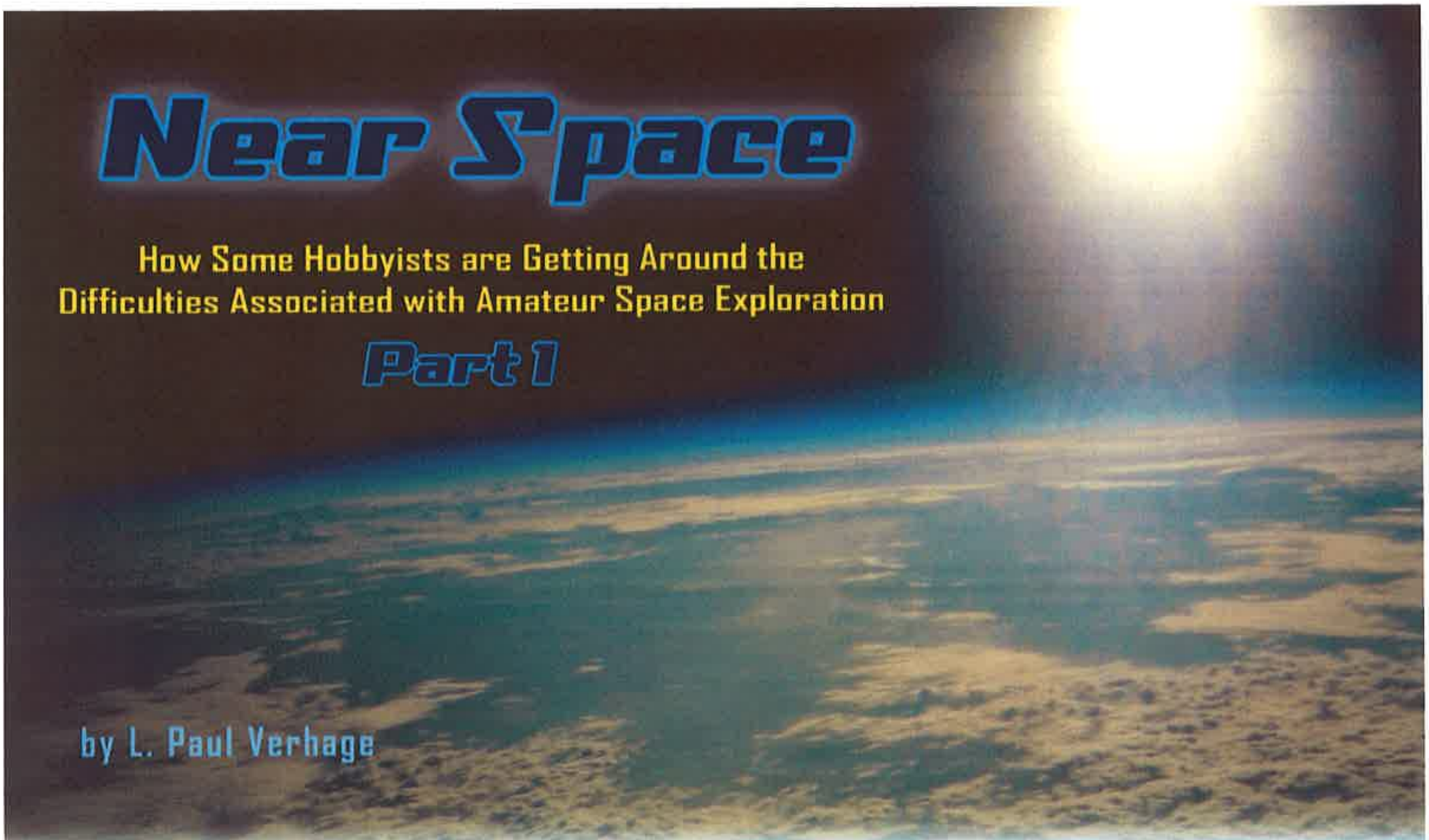
Near Space

How Some Hobbyists are Getting Around the Difficulties Associated with Amateur Space Exploration

Part 1

by L. Paul Verhage



Many of us dream of exploring space. Two outlets for this dream are amateur astronomy and rocketry. Neither of these hobbies, though, can match the sheer awe of building and launching a private spacecraft. Unfortunately, there are major roadblocks to this dream of amateur space exploration.

No doubt, you can list the many obstacles that stop us from constructing a spacecraft; my list goes like this. We cannot build our own spacecraft because of the high cost of space-rated materials, the difficulty of machining spacecraft parts, and the amount of time involved in construction. In addition, our lack of access to a clean room and our inability to properly test a spacecraft at various stages of its construction will stop us, even if we do have the necessary parts, skills, and free time.

If we manage to build a spacecraft, I can think of two additional obstacles stopping us from launching it. These after-construction obstacles are the length of time we must wait for the launch and the cost of the launch itself. How can we justify the time and money needed to assemble a spacecraft when we know that we will wait a year for launch and that we can hardly afford the launch in the first place?

Even if we construct and launch our spacecraft, there's one final obstacle: telemetry. As amateurs, we have no access to professional telemetry stations, nor can we afford to build a series of public telemetry stations around the world. If we can't collect data from our spacecraft, then we simply will not build it. Until the hobbyist can create, launch, and record data from his or her own spacecraft, there will be no such thing as amateur space exploration.

Recently though, hobbyists have found a creative solution to the dream. They substitute weather balloons and helium for costly rocket boosters. They use off-the-shelf components to assemble a functioning model of a spacecraft, and they use amateur radio for spacecraft telemetry. These few hobbyists are constructing what are called near spacecraft and launching them deep into the stratosphere, or near space. A near space program is often called the poor man's space program and it makes an amateur science hobby that is nearly out of this world.

This article explores the amateur's version of a near space program and how it solves the many obstacles mentioned above. Read this article and you'll learn how similar near space is to outer space. Then, you'll see how easy it is for the hobbyist to build his or her own near spacecraft and launch vehicle. Finally, you'll become familiar with some of the benefits of starting your own amateur near space program.

My article is too short to teach you everything you need to know; however, I hope it will convince you that an amateur near space program is a hobby that you can, and should, take up. From there, you can get the help you need from the resources listed at the end of this article.

The Earth's Atmosphere

Before learning about near space, you must first become familiar with the structure of our atmosphere.

There are five layers in our atmosphere, each with its own name and set of characteristics. We live and play in the troposphere, the lowest layer of our atmosphere. Our weather occurs in this layer and most aircraft fly in it. The troposphere extends to an altitude of around 50,000 feet at a boundary called the tropopause. The exact altitude of the tropopause depends on the time of the year and latitude.

The next highest layer is called the stratosphere. Residing in the stratosphere is the ozone layer that protects us from the sun's harmful ultraviolet radiation. Very few aircraft can fly in this layer. For the most part, we are very unaware of the stratosphere. The stratosphere extends to an altitude of around 160,000 feet at a boundary called the stratopause.

Above the stratopause is a layer of the atmosphere called the mesosphere. Only rockets and meteors travel through this layer. Above the mesosphere is the thermosphere and then the exosphere. There is a boundary between the thermosphere and exosphere (called, you guessed it, the thermopause), but no top boundary to the exosphere. Outer space exists in the two topmost layers of our atmosphere.

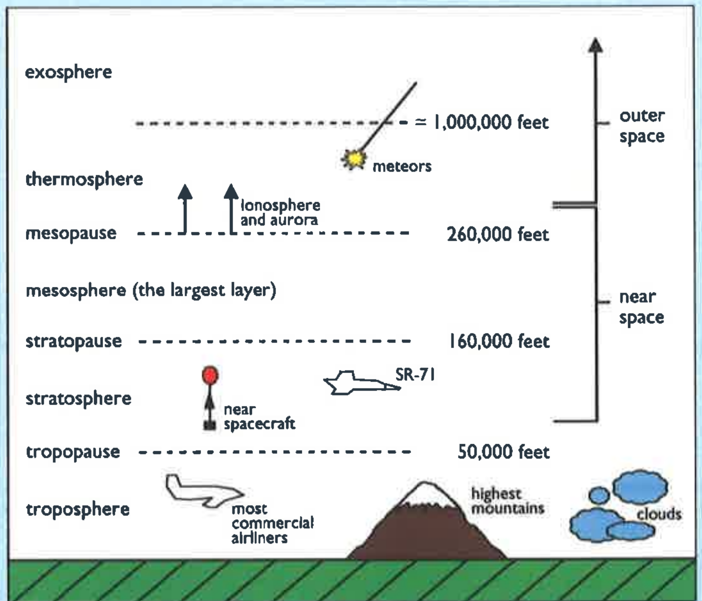
Environmental Conditions in Near Space

Now that you're familiar with the structure of our atmosphere, we can put near space into perspective by discussing its location and environmental conditions. First, where is near space located? I define near space as those altitudes in the stratosphere and mesosphere between 75,000 feet and 330,000 feet. I selected the lower boundary because of the environmental conditions found at this altitude and the higher boundary because it is the internationally defined boundary for outer space. For an altitude comparison, many of you have flown in commercial aircraft, which fly at an altitude between 30,000 and 40,000 feet.

Now, what's it like in near space? There are a number of unique conditions found in near space. The first is its temperature. Let's launch a near spacecraft and see what it tells us about temperature (please see the charts accompanying this article). As our near spacecraft ascends in the troposphere, we find that the air temperature continuously decreases. The troposphere cools with altitude because it's warmed by its contact with the ground. You might think that the troposphere should be warmed by sunlight, but, the troposphere is very transparent to sunlight, so sunlight shines right through it without warming it. Once our near spacecraft passes through the tropopause, sensors find that the air temperature stops cooling. During the summer, the tropopause occurs at an altitude of 50,000 feet for mid-latitudes and the air temperature is a chilly -60° Fahrenheit. In the winter, the tropopause lowers to an altitude of 40,000 feet and its temperature can drop to an even colder -90° Fahrenheit.

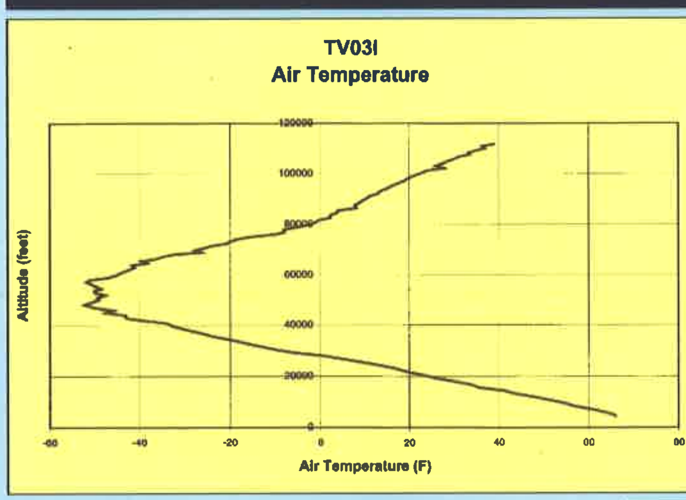
Once our near spacecraft enters the stratosphere, we find that the air temperature increases with altitude. At an altitude of 100,000 feet — which is easily reached by our near spacecraft — the air temperature can warm to 20° Fahrenheit or warmer. The stratosphere warms with increasing altitude because of its ozone content. The sun's ultraviolet radiation is blocked by our ozone layer. Recall that energy cannot be created or destroyed; it may be in another place and possibly in a new form. In the stratosphere, energy from the sun's ultraviolet radiation is eventually converted into higher air temperatures. As our near spacecraft gets closer to the sun, there is more ultraviolet radiation for the ozone to block, and, therefore, warmer air temperatures.

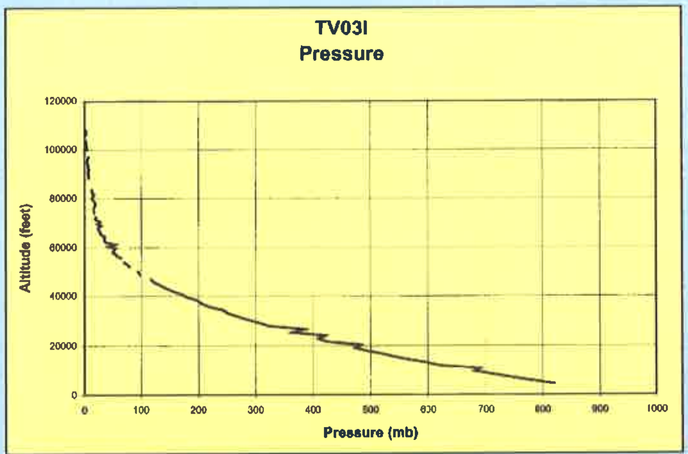
The second condition found in near space is reduced air pressure. As opposed to the up and down changes in air temperature that our near spacecraft detected, air pressure can only decrease with increasing altitude. Our near spacecraft sees air pressure dropping by a factor of two for



Layers of the Earth's atmosphere.

Air temperature cycles as altitude increases.

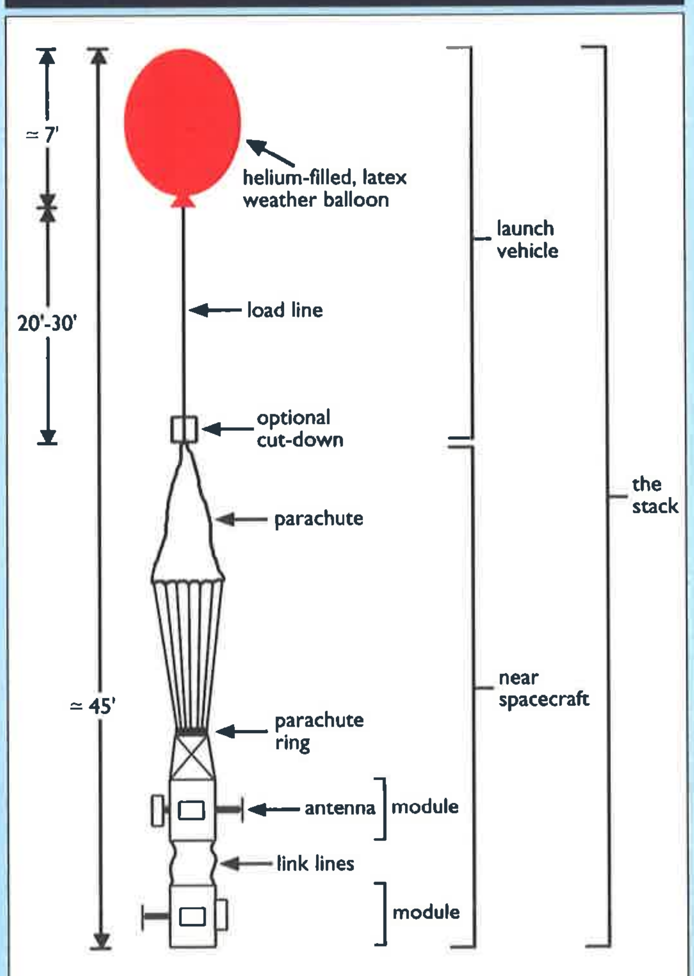




Not surprisingly, atmospheric pressure decreases with altitude.

every 18,000 foot change in altitude. At 75,000 feet, our near spacecraft measures an air pressure less than 6% of the air pressure found at sea level, or about 95% vacuum. At 100,000 feet, our near spacecraft measures an air pressure only 1% of the air pressure at sea level. It is 99% vacuum at 100,000 feet! As a result of these low air pressures, the sky becomes inky black in color. The reduction in air pressure (or more specifically, air density) has one more effect and that deals with cosmic rays. In near space, with fewer air molecules to create a shield, the cosmic ray flux is over 100 times greater than at sea level.

The "Stack"— Component parts of the integrated launch vehicle and near spacecraft.



The third condition found in near space is what happens to the earth's horizon. There are three amazing effects.

First, the distance to the horizon increases. Remember that a six foot tall adult sees a horizon that is typically three miles away. At an altitude of 75,000 feet, our near spacecraft sees a horizon that is 335 miles away. At 100,000 feet, the horizon is closer to 400 miles away. So at 100,000 feet, our near spacecraft can see our entire state in a single glance.

Another effect of altitude on the earth's horizon is that it makes the earth's curvature noticeable. Photographs taken of the earth's horizon from near space show the edge of the earth to be curved and this should be enough to satisfy the members of the Flat Earth Society (not!).

The final effect that altitude has on the earth's horizon is that the horizon gets lower. This effect is sometimes called depression of the horizon. The effect is very noticeable to astronauts on the Space Shuttle where they orbit earth at an altitude of 300 nautical miles. You don't have to orbit the earth, though, to see this effect. Even our near spacecraft can detect this effect. At an altitude of 100,000 feet, our near spacecraft sees a horizon that is more than five degrees lower than it is at sea level. So the angular distance from horizon, to zenith, to opposite horizon spans more than 190°.

The final condition found in near space that I will discuss is gravity. The higher our near spacecraft climbs, the less gravitational force earth exerts.

Now, this is not the same effect noticed by astronauts. When in orbit about the earth, an astronaut is in a state of constant freefall. As a result, s/he feels weightless. This weightlessness overwhelms the reduction of gravity due to the distance that the Space Shuttle orbits from the earth's center.

However, in near space, we can detect a change in the earth's gravity. At an altitude of 100,000 feet, the acceleration due to gravity is 1% less. Consequently, our near spacecraft weighs only 99% of its weight at sea level.

You can see that the conditions in near space look and feel much like space. There is no means for the hobbyist to create these conditions on a large scale. If we want to experience space vicariously, then the amateur near space program is the only game in town.

Getting Into Near Space

Now that you're familiar with the location and conditions found in near space, let's talk about how we get there. There are two elements to getting into near space:

the launch vehicle that does the heavy lifting and the near spacecraft that does the thinking.

The Launch Vehicle

To get into near space, you need a launch vehicle. Amateurs most frequently use a launch vehicle consisting of a latex weather balloon, helium, and a length of nylon cord. Amateurs purchase their weather balloons from either Kaymont or Kaysam (see Resources). You should expect to pay about $50.00, plus shipping, for a 1,200-gram balloon. A balloon this large has enough volume to get a 12-pound near spacecraft to an altitude of 85,000 feet. If you use a larger balloon or lower the weight of your near spacecraft, you can reach even higher altitudes.

Purchase your helium from a welding shop and never from a department store. Department store helium is fine for filling party balloons, but your 1200-gram weather balloon requires over 300 cubic feet of helium. If you purchase helium from your local welding shop, they'll sell you a purer grade of helium and a lower cost per volume.

The load line of the launch vehicle is just a length of nylon cord. This is the same kind of nylon cord or twine sold in places like hardware stores. The cord is strong enough to lift the near spacecraft and able to separate from the balloon nozzle with a minimum of force. The load line is cut to a length of between 20 to 30 feet and all its knots are wrapped in small pieces of duct tape for extra security.

The Near Spacecraft

Your near spacecraft consists of a recovery parachute and one or more modules. If more than one module is used, you will connect them together with link lines. You may also use an umbilical to share power and data between the modules. On some occasions, you might place a cutdown on the load line between the near spacecraft and its launch vehicle. A cutdown is not required, but when it is used, it separates the near spacecraft from its launch vehicle. A cutdown is used to terminate missions early or to separate the balloon remains from the parachute during the descent phase of a mission.

The Recovery Parachute

The recovery parachute protects private property and your near spacecraft. You can either purchase your parachute from a rocketry company or sew it yourself (I prefer to sew my own). Depending on the porosity of the canopy's fabric, your 13-pound near spacecraft (12 pounds for the modules and one pound for the recovery parachute) will require a parachute about six feet in diameter.

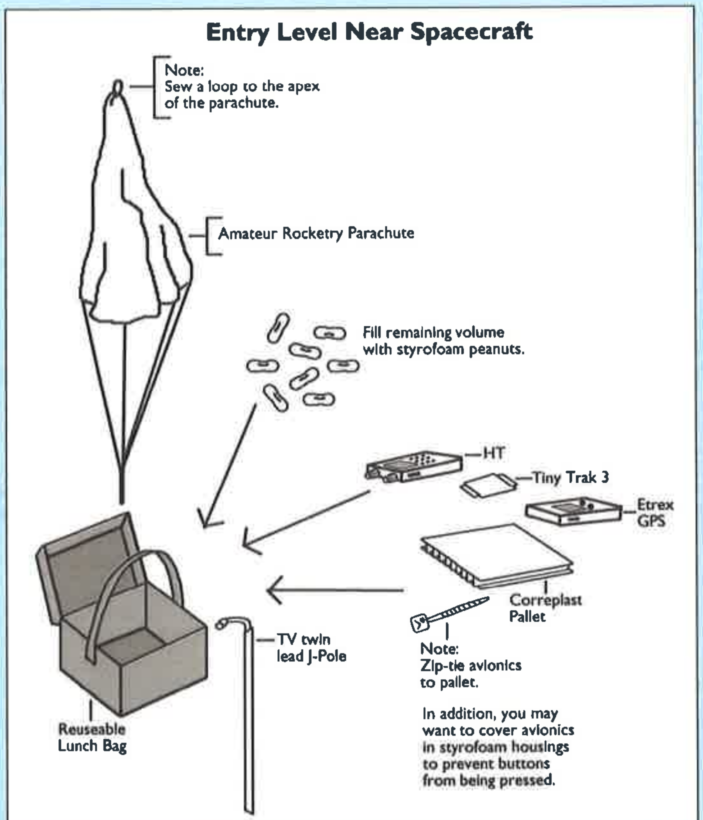
Never launch the recovery parachute folded; instead, the launch vehicle lifts the parachute by its apex in a pre-deployed position. This way, the parachute opens immediately upon balloon burst. Remember how long the load line was? It's this long to make sure that the burst balloon (which remains tied to the other end of the load line) can fall over the side of the parachute canopy, rather on top of the parachute canopy, possibly collapsing it.

Preparing for lift-off!

Modules

A module consists of an airframe, avionics, and possibly experiments. Some airframes are purchased ready to fly while others are specially constructed. The avionics are either a radio tracker or a flight computer. Some avionics are mounted to a pallet that fits inside the airframe, while others are packed in foam rubber. A pallet is a lightweight means to keep elements of the avionics from bouncing

More spacecraft than the Baikonur Cosmodrome.



Components of the near spacecraft.

around during a mission, just like foam rubber does. When possible, use a standardized airframe design and avionics pallet. This way, you can have several airframes and avionics pallets that can be mixed and matched as needed.

Experiments are the element that changes the most. Typically, each new mission switches out the old experiments for new ones. These experiments are what excite me the most about the amateur near space program.

Airframes

The fastest way to get an airframe is to purchase an insulated and reusable lunch bag. In this style of airframe, the avionics are either mounted to a sheet of correplast (a pallet) with zip ties or fitted into a block of foam rubber that has been cut to fit the interior space of the lunch bag. Never rely on the rubber ducky antenna that comes with most handheld radios, as they tend to have poor gain. Instead, use a flexible J-Pole or dipole antenna connected to the handheld radio's antenna jack. The rest of the antenna is left dangling outside of the closed bag. Parachute shroud lines are attached securely to the hand strap. Never use a snap swivel to attach the parachute to the airframe, as it can pop open. A popped snap swivel terminates a near space mission much sooner than planned. A reusable lunch bag and simple tracker, as described below, make an ideal first near spacecraft or backup tracker for a more advanced near spacecraft design.

More elaborate airframes are constructed from a 3/4" thick Styrofoam sheet. The best source of this material is the blue or pink Styrofoam sheeting used to insulate homes. This material is very popular and can be found at virtually every home improvement store. Styrofoam is the ideal material because it is strong, warm, lightweight, and inexpensive. Styrofoam is also very easy to machine; you only need a sharp Xacto knife and metal straight edge to cut the foam. A good adhesive to glue the sides of your cut Styrofoam panels together is hot glue. As it sets very quickly, hot glue is as easy to work with as Styrofoam. Just be sure to keep the glue below its maximum temperature, because it can begin to melt the Styrofoam.

After constructing your airframe, you may wish to add more insulation to its exterior. To keep spacecraft warm, aerospace companies wrap their spacecraft in multilayer insulation (MLI). Their MLI is constructed from alternating layers of space-rated aluminized Mylar or Kapton and a scrim (plastic mesh) inner layer. A homemade version of MLI is made from space blanket and wedding veil material. At this time, however, I'm not certain the vacuum of near space is "hard" enough to make the MLI effective.

During its mission, the interior of your near spacecraft module will chill in the freezing air. The cold of near space is severe to some items, like batteries. From personal experience, I can tell you that cold batteries can make for a bad day. In some cases the batteries get so cold that they fail and shut down telemetry from your near spacecraft (ever see the movie, *Lost In Near Space*?).

There are two things you can do to prevent this. The first is to use lithium cells. The chemistry of lithium cells holds up to cold much better than most other battery chemistries. The second is to cover the exterior of the airframe in dark fabrics. A jacket of dark fabric absorbs solar radiation and will passively heat the interior of the module. Besides warming the module, a fabric jacket will also protect the MLI and airframe exterior from abrasion during landing. It's also a great place to attach link lines between modules. I use ripstop nylon for my fabric jackets, which I call abrasion jackets. You've most likely seen ripstop nylon used in fabric kite sails.

Avionics for Near Space

The electronics used to operate a near spacecraft are called avionics (aviation electronics). For your first near space mission, I recommend using a simple amateur radio tracker. A simple and inexpensive amateur radio tracker consists of a terminal node controller connected to a GPS receiver and a handheld, two-meter, amateur radio (see Resources).

The terminal node controller (TNC) is a modem built for radio use. When used in avionics, it accepts sentences from a GPS receiver and formats them for transmission over the radio.

Afterwards, it keys the radio and sends the proper tones. A similar set-up on the ground decodes the tones and displays the data on a laptop or PC. This method is referred to as the Automatic Packet Reporting System (APRS) and is very popular with the amateur radio community.

Because of APRS, the position of the near spacecraft in three dimensions, its speed, and its heading are known to chase and recovery crews.

The simple tracker costs around $250.00, but don't let the cost scare you. Assembling your tracker is a one-time expense, because it is used on every mission. Besides, the cost of a tracker is less than the cost of a good set of golf clubs. Not only does a tracker cost less, but the aggravation associated with it is less than the aggravation associated with the same set of golf clubs.

The next step up from a radio tracker is a flight computer. Most of the flight computers used by amateurs today are based on programmable microcontrollers like the PIC, Rabbit, or BASIC Stamp.

Upgrading from a radio tracker to a flight computer doesn't add much to the cost of avionics, but it does permit complex experiments and mission profiles that aren't available with a simple tracker. More information on flight computers is available from groups like ANSR, Project Traveler, or myself.

Your experiments will change on each mission, but your modules shouldn't. Give some thought to designing and building a generic style of airframe and flight computer. This way experiments are designed to meet the standards for the modules, rather than having modules designed to match the experiment. Be sure to document these standards. This is a much faster approach to flying missions, making failures less likely. Now your near spacecraft is more like a Space Shuttle than a Mercury space capsule. NV

Some Helpful Websites — Amateur Near Space Programs

ANSR
www.ansr.org
Arizona

EOSS
www.eoss.org
Colorado

HABITAT
habitat.netlab.org/index.shtml
Kansas

HamBONE
frodo.bruderhof.com/hambone/index.html
New York

KNSP (1)
www.ksu.edu/humec/knsp
Kansas

NSTAR
members.cox.net/mconner1/nstar.html
Nebraska

Project Traveler
www.rckara.org/project_traveler
Kansas

Ralph Wallio (2)
users.crosspaths.net/~wallio
Iowa

TVNSP
www.voiceofidaho.org/tvnsp
Idaho

Aware Electronics
www.aw-electronics.com
RM-60

Byonics
www.byonics.com
Tiny Trak III (TNC)

Garmin
www.garmin.com
GPS Receivers

HRO
www.hamradio.com
Amateur Radios

Kantronics
www.kantronics.com
KPC 3+ (TNC)

Kaymont
www.kaymont.com
Weather Balloons

Kaysam
www.kaysam.com
Weather Balloons

Parallax
www.parallax.com
BASIC Stamps

Rocketman
www.the-rocketman.com
Parachutes

APRS/Packet Radio
www.tapr.org
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ARRL
www.arrl.org
Amateur Radio Clubs